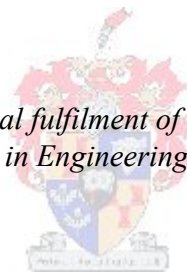


An Unmanned Aircraft System for Maritime Search and Rescue

by
Andre Paul Meredith

*Thesis presented in partial fulfilment of the requirements for the degree
of Master of Science in Engineering at Stellenbosch University*



Supervisor: Prof Thomas Jones
Department of Electrical and Electronic Engineering

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: March 2011

Abstract

Search and Rescue is an essential service provided by States and Militaries to search for, locate and rescue survivors of accidents and incidents. Civil Search and Rescue utilizes a system of well-trained professionals or volunteers, an effective Search and Rescue organization, supported by industry and other providers of infrastructure and assets. The service is rendered to save the lives of civilian individuals in imminent danger of losing their lives. Military (Combat) Search and Rescue is provided by militaries to save the lives of military practitioners in a similar predicament. In addition, Search and Rescue is performed over land and over the sea.

All forms of Search and Rescue rely on capable, specialized assets for efficiency and affectivity. Assets are specified and chosen on the grounds of various factors, amongst others operating environment, operational profile, performance and special abilities.

This thesis has determined the need for a Search and Rescue asset, capable of performing effective and efficient Search and Rescue over the entire national maritime Search and Rescue Region, up to the Region extremities. An analysis was performed to prove this deficit, and quantify the key performance and special equipment requirements for such an asset. An analysis was also performed which proves that an Unmanned Aircraft System should be an ideal choice to meet this need. Finally, an Unmanned Aircraft System concept was specified that could potentially meet this need.

Opsomming

Soek en Redding is 'n essentiële diens wat deur State en militere organisasies gebied word om oorlewendes van ongelukke en insidente te soek, op te spoor en na veiligheid te bring. Siviele Soek en Redding maak gebruik van 'n stelsel van goed-opgeleide professionele persone, sowel as vrywilligers, asook 'n effektiewe Soek en Reddingsorganisasie, ondersteun deur die industrie en ander voorsieners van infrastruktuur en toerusting. Dergelyke dienste word daargestel om die lewens van siviele persone, wie se lewens in gevaar is, te red. Militere Soek en Redding word deur militere organisasies daargetel om die lewens van militere persone, wie in gevaar is, te red. Soek en Redding word oor land sowel as oor die see uitgevoer.

Alle vorms van Soek en Redding maak staat op die beskikbaarheid van gespesialiseerde toerusting met gespesialiseerde gebruiksaanwending, vir maksimale effektiwiteit en doeltreffendheid. Toerusting word gekies op grond van verskeie faktore, onder meer die gebruiksomgewing, operasionele profiele, verlangde prestasie en spesiale vermoëns.

Hierdie tesis het die behoefte aan 'n gespesialiseerde Soek en Redding platform, wat die vermoë het om effektiewe en doeltreffende Soek en Redding uit te voer oor die hele nasionale Soek en Redding Gebied, tot en met die ekstreme daarvan, vasgestel. 'n Analise is uitgevoer om hierdie tekortkoming uit te wys, asook om die sleutel prestasie- en gespesialiseerde toerustingbehoefte vir so 'n platform te kwantifiseer. 'n Verdere analise is uitgevoer om te bewys dat 'n Onbemande Vliegtuig die beste opsie sou wees vir 'n platform om aan hierdie behoeftes te voldoen. Ten slotte is 'n konsep vir 'n Onbemande Vliegtuig Stelsel voorgetel wat potensieel hierdie behoefte sou kon vervul.

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Abbreviations

Abbreviation	Explanation
ACAS	Airborne Collision and Avoidance System
ADS-B	Automatic Dependent Surveillance Broadcast
AEC	Africa Economic Community
AEW&C	Airborne Early Warning and Control
ALSC	Aid Life Supply Canister
ARCC	Aeronautical Rescue Coordination Centre
ARS	Automatic Recovery System
ASAS	Association of Southern African States
ASL	Above Sea Level
ATC	Air Traffic Control
AU	African Union
AVWS	Air Vehicle Workstation
BAMS	Broad Area Maritime Surveillance
BLOS	Beyond Line-of-Sight
C&C	Command and Control
C&MCZ	Contiguous & Maritime Cultural Zone
CAR	Civil Aviation Regulations
CM	Continental Margin
CS	Continental Shelf
CZ	Contiguous Zone
DF	Direction Finder
DOT	Department of Transport
E-W	East-West
EEZ	Exclusive Economic Zone
ELT	Emergency Locator Transmitter
EO/IR	Electro-Optical Infrared
EPIRB	Emergency Position Indicator Radio Beacon
EUROCAE	European Organisation for Civil Aviation Equipment
FLIR	Forward Looking Infrared
ft	Feet
FTS	Flight Termination System
FY	Fiscal Year
Gbit/s	Gigabits per second
GCS	Ground Control Station
GDP	Gross Domestic Product
GHz	Gigahertz
h	Hours
HALE	High Altitude and Long Endurance
HF	High Frequency
ICAO	International Civil Aviation Organisation
IHO	International Hydrographic Organisation
ILS	Instrument Landing System
IMO	International Maritime Organisation
in	Inches
IR	Infrared

ISDSC	Inter-State Defence and Security Committee
IUCN	International Union for Conservation of Nature and Natural Resources
kg	Kilogram
kn	Knot
LALE	Low Altitude and Long Endurance
lb	Pounds
lbf	Pounds-force
L/D	Lift-to-Drag Ratio
LOS	Line-of-Sight
LRLE	Long Range and Long Endurance
MALE	Medium Altitude and Long Endurance
MAUW	Maximum All-Up Weight
MAV	Micro Air Vehicle
Mbit/s	Megabits per second
MCZ	Maritime Cultural Zone
METAREA	Meteorological Area
MHz	Megahertz
min	Minutes
MIR	Marion Island Rim
MLM	Marine Location Marker
MRCC	Maritime Rescue Coordination Centre
MSR	Maritime Search Radar or Maritime Surveillance Radar
MSWS	Mission Specialist Workstation
N	Newton
NATO	North Atlantic Treaty Organisation
NEPAD	New Partnership for African Development
nmi	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
NPA	National Ports Authority
NSRI	National Sea Rescue Institute
OAU	Organisation of African Unity
OBOGS	On-Board Oxygen Generation and Supply
OEM	Original Equipment Manufacturer
PECSAR	Permanent Executive Committee for Search and Rescue
PLB	Personal Locator Beacon
PWS	Payload Workstation
RCC	Rescue Coordination Centre
RSC	Rescue Sub-centre
RSE	Range, Speed, Endurance
SAA	South African Airways
SAAF	South African Air Force
SADC	Southern African Development Community
SAFAIR	South African Freight Air
SAN	South African Navy
SANAP	South African National Antarctic Program
SANDF	South African National Defence Force
SAPS	South African Police Services

SAR	Search and Rescue
SASAR	South African Search and Rescue Organisation
SATCOM	Satellite Communication
SE	Search Extremities
SMC	Standing Maritime Committee
SOLAS	Safety of Life at Sea
RPV	Remotely Piloted Vehicle
SRR	Search and Rescue Region
SRS	Search and Rescue Sub-region
TCAS	Terrain Collision Avoidance System
TW	Territorial Waters
T/W	Thrust-to-Weight Ratio
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Air Vehicle
UHF	Ultra High Frequency
US	United States
UNCLOS	United Nations Convention on the Law of the Sea
USAF	United States Air Force
USMC	United States Marine Corps
VHF	Very High Frequency
WMO	World Meteorological Organisation
W/S	Wing Loading
WWI	World War I
WWII	World War II

PART 1

Maritime Search and Rescue in South Africa

Chapter 1

1. Introduction

The importance and usefulness of aircraft, both military and civilian, has been well known for decades; they have been used for a myriad of tasks and in various roles and configurations, by numerous users, in all possible environments. The marine environment is no different and has also benefited from aircraft; they have been instrumental in the safeguarding and preservation of South Africa's oceans, marine resources, coastlines, protected areas, coastal infrastructure and trade routes, and in the provision of essential civil services.

One of the primary roles attributed to aircraft is the provision of airborne Search and Rescue (SAR) capabilities. Airborne systems are capable of covering large areas in a short time span, thereby improving the chances for success of a SAR mission.

Maritime Search and Rescue poses a unique set of problems when compared with overland Search and Rescue. Oceans have no landing strips, airports, fuel stops or other such facilities where rescue aircraft can land to replenish or be repaired. The oceans provide no shade, drinkable water, warmth, hard ground to sleep on, or shelter at night, for those in distress. Furthermore, the oceans are harsh and largely unpredictable, and cover a huge expanse of uncharted area of the planet.

For these reasons, countries bordering the oceans are given the responsibility to provide essential maritime Search and Rescue services for the portion they border. The area of responsibility differs from county to country, depending on the coastline length and geographic location.

At present, South Africa utilises a varied contingency of aircraft to provide maritime Search and Rescue services. Most of these assets provide short to medium range and short to medium endurance capabilities, and are duly employed. The problem is that, due to its vastness, no airborne asset is

currently available capable of providing effective and efficient SAR services across the entire South African SAR region.

1.1. Aim

This thesis aims at providing a solution to this problem by developing and specifying a concept for an Unmanned Aircraft System that could fulfil South Africa's Long Range and Long Endurance (LRLE) maritime Search and Rescue requirements.

1.2. Scope

The following primary objectives were set for this thesis:

- Evaluation of the marine environment of South Africa;
- Evaluation of the South African Search and Rescue organisation, structures and responsibilities;
- Determination of the deficit in the long range, persistent search environment;
- Concept specification of an Unmanned Aircraft System capable of bridging the deficit and fulfilling the aim of this thesis.

1.3. Outline

The thesis is broken into two Parts.

1.3.1. Part 1

Part 1 contains much of the results of the literature study leading up to the actual System Specification. Part 1 contains ten chapters.

Chapter 1 contains the Introduction, Aim, Scope and Outline.

Chapter 2 contains an analysis of the environmental, climatic and physical characteristics of our bordering oceans.

Chapter 3 contains an analysis of the diverse marine-related activities in and around our oceans, with their potential influence on Search and Rescue requirements.

Chapter 4 discusses our National Search and Rescue Organisation and affiliated systems, defines our Search and Rescue Region, and highlights our associated Search and Rescue responsibilities.

Chapter 5 formulates the performance requirement, in terms of key performance parameters, for an aircraft capable of meeting the Aim of this thesis.

Chapter 6 defines the special Search and Rescue special equipment minimums for a SAR aircraft capable of meeting the Aim of this thesis.

Chapter 7 provides a consolidation of national airborne assets available for maritime Search and Rescue.

Chapter 8 provides a consolidation of foreign airborne assets available for maritime Search and Rescue.

Chapter 9 provides a consolidation of unmanned aircraft assets available for maritime Search and Rescue.

Chapter 10 contains a comparative analysis between performance- and special equipment level requirements, and existing national, foreign and unmanned systems. The comparative study is used to determine shortfalls, and act as motivator for the continuation of the concept specification for an aircraft capable of bridging the shortfalls.

1.3.2. Part 2

Part 2 contains the System Specification and Concept for an Unmanned Aircraft System capable of meeting the Aim of this thesis.

Chapter 11 provides background on Unmanned Aircraft, including the definition of an Unmanned Aircraft and Unmanned Aircraft System; history of Unmanned Aircraft; and UAV categorisation methods.

Chapter 12 analyses the advantages and disadvantages of Unmanned Aircraft, when compared with manned aircraft.

Chapter 13 provides a summary of the Unmanned Aircraft System elements as analysed for this thesis.

Chapter 14 provides a summary of the results obtained from the analytical processes followed for the determination of the basic weights, dimensions and powerplant requirements for the Aircraft.

Chapter 15 provides a summary of the payloads selected for this concept, as well as basic characteristic for each payload.

Chapter 16 provides the concept for the data links employed.

Chapter 17 discusses the aircraft emergency recovery and flight termination concepts.

Chapter 18 discusses conceptual characteristics of the ground elements, including the Ground Control Station, launch and recovery, emergency ground power, storage and transportation elements.

Chapter 2

2. National Oceanographic Characteristics

South Africa is bordered by one of the longest coastlines in Africa, possesses extensive marine and offshore mineral resources and, due to its location halfway between the West and the East, supports a significant and very active shipping industry. It is also notorious amongst seafarers for its rough and often unpredictable offshore weather conditions, which has led to the demise of a multitude of ships.

The focus of this thesis is on maritime Search and Rescue (SAR). It is therefore necessary to study and analyse the marine environment of Southern Africa, with particular focus on aspects that could potentially complicate SAR operations. This section provides an outline of some of the natural characteristics and political boundaries associated with the nation's coasts and oceans.

2.1. Environmental, Physical and Climatic Characteristics

2.1.1. Coastline Length and Limits

The official length of the South African coastline is 2,798km^[1]. The coastline stretches from the border between South Africa and Namibia on the west (near Alexander Bay), to the border between South Africa and Mozambique on the east (near Kosi Bay).

Our coasts are bordered by three major oceans and oceanic currents:

- In the west by the Atlantic Ocean;
- In the south by the Benguela Upwelling and Agulhas Current;
- In the east by the Indian Ocean.

2.1.2. Coastal Populace

The percentage of the national population living within the 100km-wide Coastal Band is close on 40%^[2] of the total national populace. A significant

number of people therefore live very close to the sea, requiring a strong focus on essential services and support to these regions.

2.1.3. Sea States and Wave Height

The seas around Southern Africa are among the roughest in the World. Wave height measured in the seas around the Cape Peninsula and the Southern Oceans reaches 7 to 8 meters on a typical summer's day, and well beyond 8 meters further out to sea, beyond the Continental Shelf. Appendix A provides detailed information and references.

2.1.4. Wind Speeds

Although coastal conditions appear moderate, average wind speeds between South Africa and Antarctica are above 11 meters per second, among the highest in the World. Appendix A provides detailed information and references.

2.1.5. Oceanic Currents

Southern Africa is bordered by three major ocean currents: the Antarctic Circumpolar, Agulhas and Benguela^{[16][17][18]}. The Antarctic Circumpolar Current, which runs in an easterly direction above Antarctica, is the largest wind-driven ocean current in the World. The Agulhas Current requires ships to closely navigate the eastern coast of Southern Africa, when travelling from west to east. This coastal region abounds with many sharp submerged rocks and coral reefs, requiring navigation with great care^{[17][19][20]}. Modern ships with sophisticated navigational aides still end up wrecked along this treacherous stretch of coastline from time to time, due to these conditions^{[17][19][20]}. The cold Benguela Current runs along the west coast. Where the Agulhas and Benguela currents meet, there is a strong upwelling^[20], further exacerbated by prevailing strong Westerly winds (known as the "Roaring Forties") and the cold Antarctic Circumpolar Current flowing in the same direction. The results^[20] are powerful winter storms and mammoth freak waves, which can range up to 30 metres^[20] high, capable of severely damaging or sinking large ships. Appendix A provides detailed information and references.

2.1.6. Tides

African tides are at their most extreme at the very southern tip of South Africa, and on the African east coast, reaching maximum amplitude differences of up to 80cm. This is equivalent to some the larger tidal changes found across the globe. Appendix A provides detailed information and references.

2.1.7. Ocean Surface Temperatures

The average annual sea surface temperatures around Southern Africa, up to the Continental Shelf, ranges between 16 and 30°C. However, temperatures drop sharply beyond the Continental Shelf, falling to a minimum of -2°C between the Shelf and Antarctic coastline^[22]. Furthermore, the presence of ice is abundant in this oceanic region. Appendix A provides detailed information and references.

2.1.8. Air Temperatures

Air temperatures at sea level for the oceanic region below South Africa, between the Continental Shelf and the Antarctic coastline, ranges between 10 and -15°C^[24]. The combined effect of low air and water temperatures for this region is potentially lethal, should anyone find themselves in such a predicament. Appendix A provides detailed information and references.

2.1.9. A Case Study: The Marion and Prince Edward Island Group

The Marion/Prince Edward Island Group lies at 46°52'34" South 37°51'32" East in the Southern Indian Ocean^[25], approximately 1770km south-east of Port Elizabeth^[26]. This Island Group forms part of the territorial claim of South Africa^{[247][248]}, including its surrounding Oceanic Territory (blue zones in Figure 2.2). Marion Island lies within the notorious "Roaring Forties" (the band between 40° and 50° South^{[25][27][28]}) in METAREA VII^[29], illustrated in Figure 2.1^[29] below. The climatic summary for Marion Island is as follows^{[27][30]}:

- Temperatures
 - Average Annual Outside Air Temperature: 5°C
 - Average Annual Maximum Outside Air Temperature: 8.1°C

- Average Annual Minimum Outside Air Temperature: 2.8°C
- Absolute Minimum Outside Air Temperature: -6.8°C
- Average Annual Maximum Sea Surface Temperature: 10°C
- Average Annual Minimum Sea Surface Temperature: 3°C
- Wind Speeds
 - 55km/h+ Gale Force wind: 107 days per year average
 - 160km/h+ Gusts: frequently
 - 200km/h+ Gusts: periodically
 - Cyclones: 100 to 130 per year
- Tidal swells: ranging from small (70cm) to exceptionally large (12m)
- Ocean Currents: borders the Antarctic Circumpolar Current

This is representative of the climatic and oceanic conditions within areas around the Marion/Prince Edward Island Group, for which South Africa is custodian and ultimately responsible. It is also largely representative of the climatic and oceanic conditions encountered within the band between 40° and 50° south. This is evident when comparing data (wind speed, sea surface- and air temperatures) in this band with that provided for Marion Island. This band of rough and unpredictable Ocean is used by Antarctic supply- and research vessels and vessels tending the Islands in or near this zone (typically Marion, Crozet, St Paul, Tristan da Cunha, Bouvet and Gough Islands)^[31].

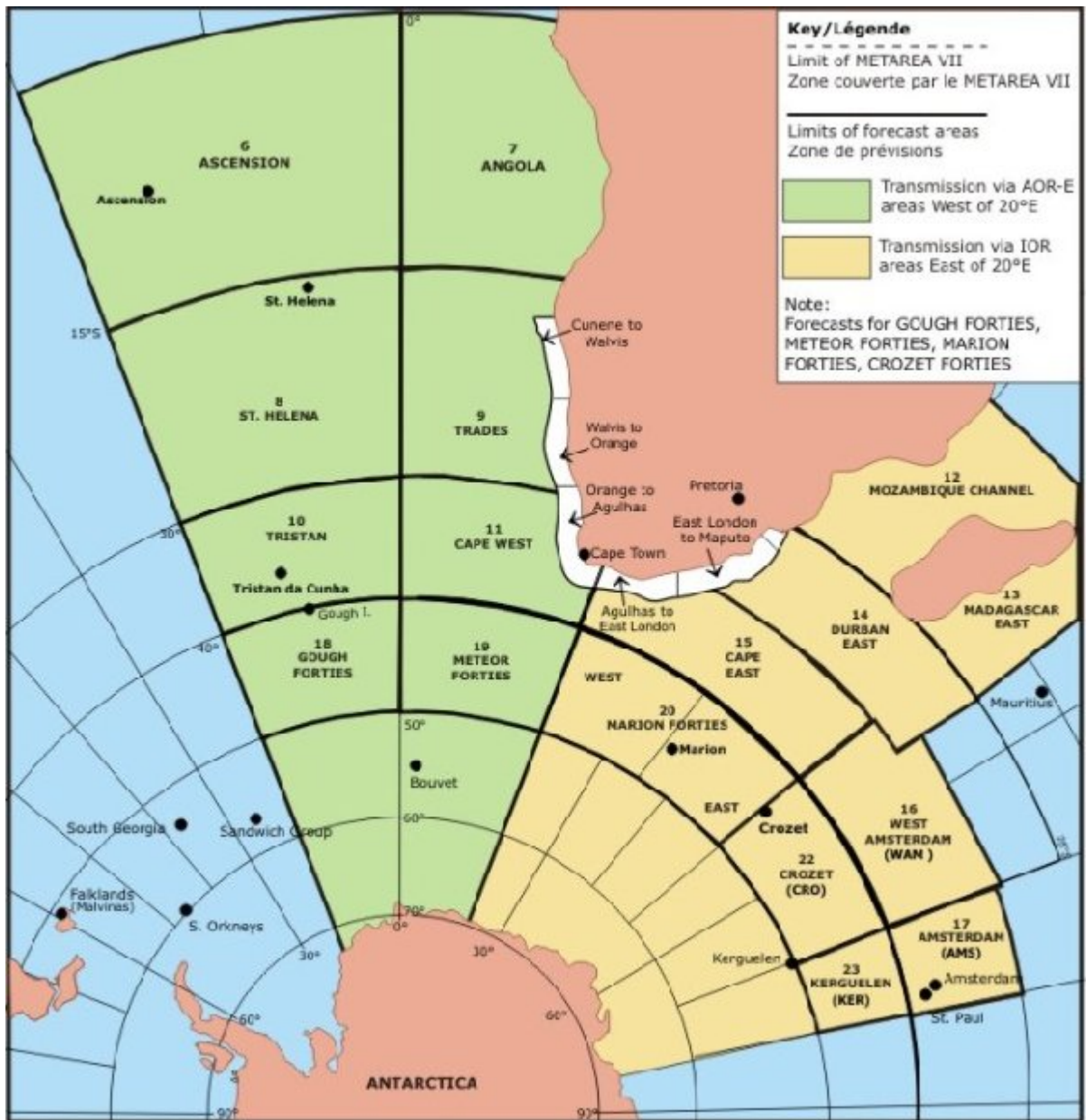


Figure 2.1: Marion and METAREA VII^[29]

2.2. National Demarcated Maritime Zones (Maritime Claims)

2.2.1. General

Countries bordering the oceans have certain “ownership rights” to the bordering portions of the sea^{[32][33]}. The ownership rights are coupled to pre-defined zones, also known as Maritime Claims. With ownership comes responsibility, and nations bordering the oceans are responsible for conservation within and management of these zones. The four Maritime Claim zones are^{[34][35]}:

- Territorial Waters
- Contiguous Zone
- Exclusive Economic Zone
- Continental Shelf

South Africa has expanded on the concept of the Contiguous Zone, and adds to it the Maritime Cultural Zone^[38].

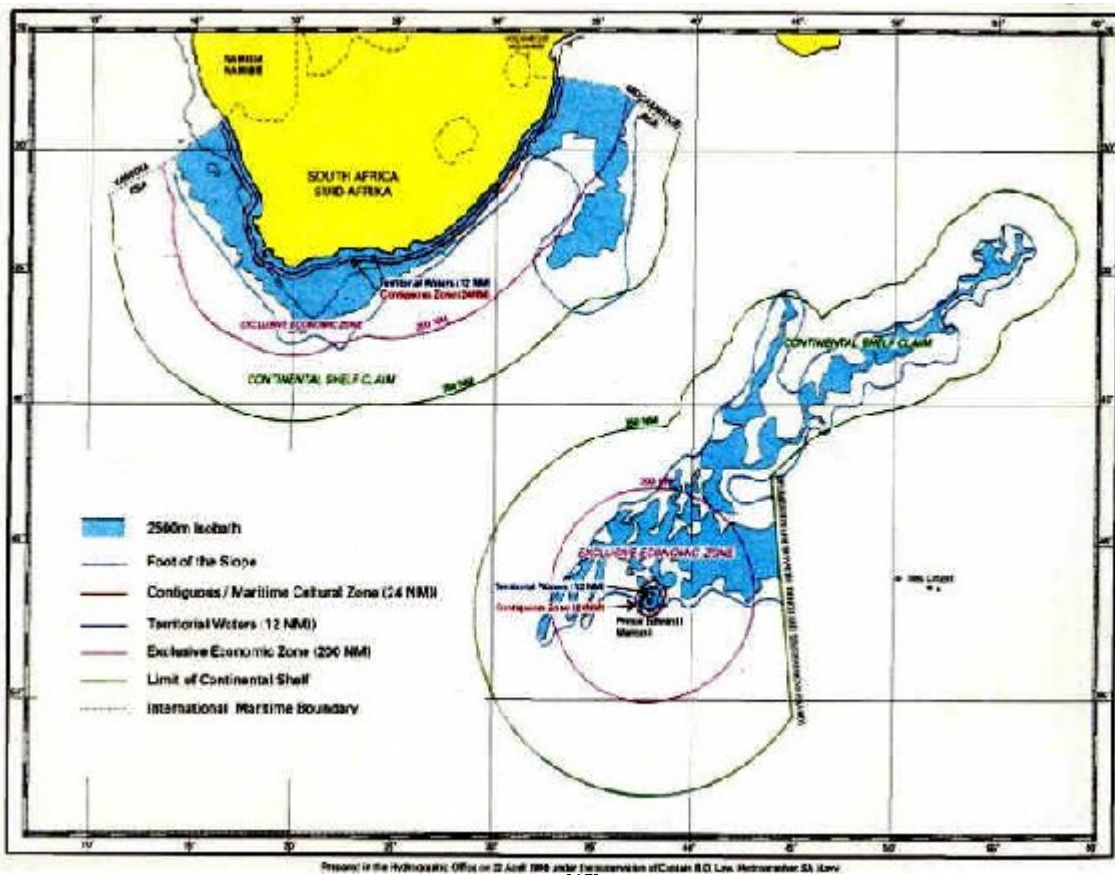


Figure 2.2: South African Maritime Claims^[45]

2.2.2. Territorial Waters (TW)

Under the United Nations Convention on the Law of the Sea (UNCLOS), a State bordered by the sea retains full territorial sovereignty up to 12nmi offshore. This 12nmi band is known as the Territorial Waters^[36].

2.2.3. Contiguous Zone (CZ)

Under the UNCLOS, the Contiguous Zone (CZ) extends from the coastline of a Coastal State, up to 24nmi seaward. The bordering nation shall have the right to exercise all the powers which may be considered necessary to prevent contravention of any fiscal law or any customs, emigration, immigration or sanitary law and to make such contravention punishable, within this zone^[37].

2.2.4. Maritime Cultural Zone (MCZ)

Under the Maritime Zones Act no 15 of 1994, the Contiguous and Maritime Cultural Zone extends from the coastline of a Coastal State, up to 24nmi seaward. The bordering nation has full control over any archaeological and historic finds within this zone^[38].

For the purposes of this analysis, the Contiguous Zone and Maritime Cultural Zone will be viewed as the singular Contiguous and Maritime Cultural Zone (C&MCZ), due to the equal size of the two zones.

2.2.5. Exclusive Economic Zone (EEZ)

Under the UNCLOS, the Exclusive Economic Zone is defined as a 200nmi zone bordering a Coastal State. Coastal States may claim this zone for exploration, exploitation, conservation and management of all natural resources in the seabed, its subsoil and overlaying waters^[39]. The EEZ for South Africa covers an oceanographic area of approximately 1,553,000km²^[40], and includes^{[32][41]} the EEZ area around the Marion and Prince Edward Island Group.

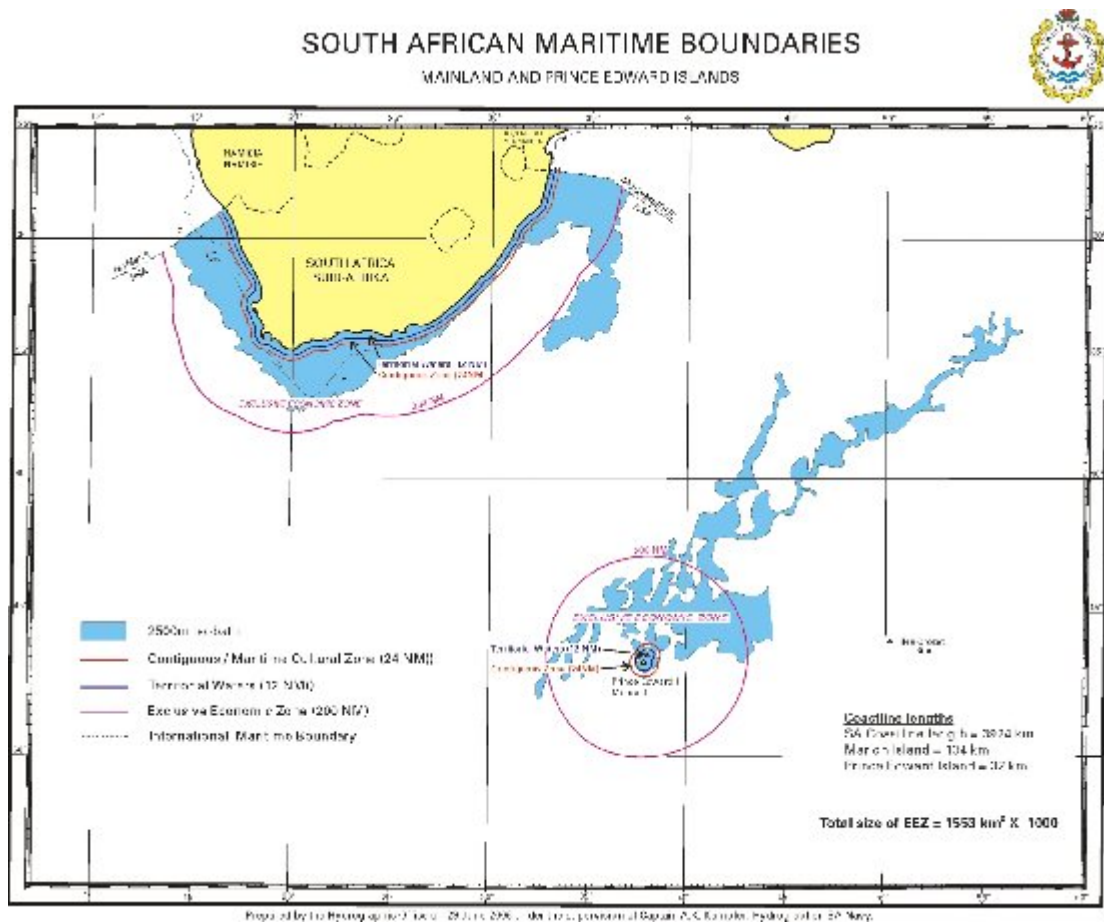


Figure 2.3: South African Exclusive Economic Zone^[40]

2.2.6. Continental Shelf (CS)

According to UNCLOS, the Continental Shelf of a coastal State comprises the submerged prolongation of the land territory of the Coastal State^[42]. This portion is the seabed and subsoil of the undersea area that extends beyond its Territorial Waters, to the outer edge of the Continental Margin (CM), or to a distance of 200nmi, where the real outer edge of the CM is short and does not extend up to that distance. It does not include the Deep Ocean floor with its oceanic ridges or its subsoil. According to Article 76 of the UNCLOS, the Coastal State may establish the outer limits of its Continental Shelf wherever the CM extends beyond 200nmi, by establishing the foot of the continental slope, and by meeting the requirements of Article 76 of the UNCLOS, paragraphs 4 – 7^[42].

Following this process, South Africa has established the limits of its Continental Shelf, and it is published in the Maritime Zones Act no 15 of 1994^[43]. From Figure 2.2 it can be seen that our Continental Shelf extends to 350nmi, on average, from the coastline^{[44][45]}.

The CS is important for the Economy, since the Maritime Zones Act no 15 of 1994 states that the South African CS claim may be utilised for exploration and exploitation of natural resources and mining of precious stones, metals or minerals, including natural oil^[46].

2.3. Conclusion

In conclusion, it is evident that the oceans bordering Southern Africa are amongst the roughest, coldest and most hostile in the world. This is particularly true for the portions beyond the Continental Shelf, where high sea states, giant waves, strong currents, icy water and air temperatures and strong (often gale force) winds are commonplace. Persons in distress in such conditions do not stand a chance of survival, unless an effective and efficient Search and Rescue system, with highly specialised and capable assets, are on hand.

Chapter 2 will investigate the levels of marine activity in and around our coasts and oceans, to determine where maritime SAR should be focused.

Chapter 3

3. Marine Activity

Chapter 1 concluded with certainty that South Africa is bordered by some of the most hostile oceans in the World, requiring a definite maritime Search and Rescue capability. Search and Rescue services are employed to search for and save the lives of people in distress. It would therefore be beneficial to know which portions of our oceans are frequented by humans; any area where humans could possibly enter or pass through should be reachable and effectively and efficiently serviced by SAR services.

3.1. Marine Resources

3.1.1. *Living Resources: Fish and Shellfish*

The oceans around Southern Africa are home to some of the richest and most productive fishing zones in the World^{[47][48]}, and as a result attract large volumes of commercial, recreational and sustenance fishing annually. South Africa provides the right for the exploitation of 20 different commercial fisheries^[49]. These include the following species of fish and marine life^[49]:

- Hake
- South Coast and West Coast Rock Lobster
- Abalone, mussels and oysters
- Tuna and Swordfish (large pelagic fish)
- Anchovies and Pilchards (small pelagic fish)
- Squid and prawns
- Mackerel
- Patagonian Toothfish
- 150 species of Line Fish

The richness of our fish resources is predominantly the result of prevalent features in our oceans, such as the presence of upwelling, ocean temperatures, large biomass production, currents and ocean topography^{[47][48]}. South Africa has promulgated the Sea Fisheries Act, Act 12 of 1988, which includes as policy guidelines the conservation of marine ecosystems and the optimal and sustainable utilisation of marine resources

Most commercial fishing takes place between the coast and the Continental Shelf, since this is where the greatest volumes of fish are found^{[48][51]}. Some species (tunas, Patagonian toothfish, shad, dorado, mackerels) are, however, found outside this zone^[50], and this implies that certain fishing vessel types do move beyond the CS, into the roughest seas, very far from the coast. Refer to Appendix B contains a detailed analysis of the natural habitats of fish species around Southern Africa.

A large and healthy fishing industry^[247] implies many fishing vessels and boats, and plenty of activity in the sea. The following are some facts and figures wrt boats, ships and vessels used for fishing in South Africa:

- Number of fishing vessels above 25 gross tons on the National register: approximately 600^[31]
- Number of licensed fishing vessels below 25 gross tons: in the tens of thousands (8285 boats for Cape Town only)^[31]
- Between 2002 and 2007, 93 SA-registered fishing vessels were involved in incidents at sea, resulting in 56 fatalities^[52]
- It is very difficult to estimate the number of illegal fishing vessels entering our Oceans each year, although high numbers are estimated^[31]
- Annual fishing capture statistics:
 - Total capture (pelagic and demersal) (2007 figures): 670,571 tons^[53]

- Total capture (pelagic and demersal) (2005 figures): 817,666 tons^[53]
- Total pelagic capture (sardines, redeye, anchovy, horse mackerel) (2005 figures): 569,083 tons^[54]

3.1.2. Minerals and Energy

South Africa is the World's top producer of platinum, manganese, chrome and vanadium, and second-largest producer of gold, zirconium and titanium^[55]. South Africa is also the World's fourth largest diamond producer^[55]. A significant portion of the Gross Domestic Product (GDP) of South Africa is dependant on its extensive mining resources and associated programs. In 2007, mining contributed R135.6 billion, or 7.7%, to the GDP^[56]. Continued exploitation of these resources is therefore vital to the sustainability and growth of the economy.

South Africa has large quantities of shore-based and offshore minerals and other natural resources, with primary focus on oil (crude petroleum), natural gas, diamonds (marine), titanium and zirconium^{[57][247]}.

Of the five primary marine mining operations, only marine diamond mining, and oil and natural gas excavation, exposes ships and personnel to potential maritime dangers, and all well within the Exclusive Economic Zone. Appendix C contains a detailed analysis of the locations and methods used for the five marine mining activities.

3.2. Commercial Shipping

3.2.1. Major Ports

Seven^[72] major ports and ten^[72] dry docks, repair quays and slipways serve as berthing and repair facilities for commercial shipping docking in South Africa. An eighth major port (Port of Ngqura) is currently under construction adjacent the Coega Industrial Development Zone in the Eastern Cape^[73]. Additionally, Simonstown is host to a Naval dock. The major ports, dry docks and repair facilities are as follows^[72]:

- Port of Saldanha Bay
- Port of Cape Town (includes two Dry Docks and one Repair Quay)^[74]
- Port of Mossel Bay (includes one Repair Slipway)^[75]
- Port of Port Elizabeth (includes one Repair Slipway)^[76]
- Port of East London (includes one Dry Dock)^[77]
- Port of Durban (includes one Graving Dock, one Floating Dock and one Repair Slipway)^[78]
- Port of Richards Bay (includes one Repair Slipway)^[79]
- SA Naval Dockyard Simonstown (includes one Dry Dock and one Synchro Lift)^[80]

The greatest concentration of commercial shipping around our coasts and in our seas is found in and around the major ports and along the shipping lanes.

3.2.2. Commercial Shipping Activity

Due to its location halfway between the West and the East, South Africa is host to one of the busiest shipping routes in the World^[247]. Figures 3.1 and 3.2 show how the primary East-West shipping lanes pass via South Africa^{[81][82]}. The only viable alternative^{[83][85][86]} for ships travelling between the East and the West is via the Suez Canal in North Africa. The alarming increase in piracy near the Horn of Africa has forced many major shipping operators to reconsider choosing to take the longer trip around the Cape^{[84][87][88]}, this could lead to an increase of between 15,000 and 40,000 vessels per year, the estimated number of ships currently using the Suez Canal annually^[84].

South Africa ranks among the top 12^[90] Maritime Trading Nations, commanding 6%^[90] of the total World Sea Trade. The following statistics provide an idea of the level of commercial marine shipping activity prevalent around our coasts:

- Commercial ships passing the Cape of Good Hope annually without docking, taking cargo from the East to the West and vice versa: 4,000+^[91]
- Commercial ships docking in South African ports annually: 13,074^[92]
- Gross tonnage of cargo handled in South Africa's seven major ports annually: 182,735,369 metric tons^[93]
- Total number of containers handled in South Africa's seven major ports annually: 4,334,612^[94]
- Revenue generated by National Port Authority as a result of bulk cargo throughput (in- and exports) in 2008/09FY: R7.11 Billion^[95]
- Revenue generated by Port Terminals as a result of container cargo throughput (in- and exports) in 2008/09FY: R5.037 Billion^[95]
- 98% of National exports by weight, is shipped by sea annually^[96]

3.3. Naval Operations

The role of the SA Navy involves the safeguarding, patrolling, policing and protecting of our national maritime borders and zones. These include the Territorial-, Contiguous-, Exclusive Economic- and Continental Shelf zones of the country, and includes the Prince Edward/Marion Island Group^[45]. Other specialised roles include hydrographic and surveying services, search and rescue, regional naval cooperation, international exercises, relief operations, and humanitarian assistance^[45].

This requires a Naval Fleet capable of operating anywhere within our sovereign waters, and beyond. The Search and Rescue role alone necessitates the Navy to operate the entire national Search and Rescue

Region, which, according to the Navy, covers an area of more than 17.2 million km²^[45], and extends well beyond the Continental Shelf. The survey ship also undertakes regular trips to Antarctica, almost 3000nmi from South Africa's coast.

The SA Navy currently operates a mixed fleet of four frigates, three submarines, four coastal minesweepers, four coastal minehunters, one fleet replenishment ship, five missile fast attack craft, three inshore patrol vessels, twenty-six harbour patrol boats and one survey ship^[97]. The SA Navy currently owns no aircraft of its own, but utilises the services of the SA Air Force for maritime air support.

3.4. Maritime Police Services

The SA Police Service roles include the policing and safeguarding of our national borders against crime. This includes the maritime borders and maritime zones, up to and including the Exclusive Economic Zone^[98].

3.5. Leisure

3.5.1. Coastal Tourism

The South African coast is dotted with hundreds of resorts, hotels and holiday venues. Tourism accounted for R194.5 billion of our national GDP in 2008^[99]. Our coasts attract thousands of tourists, holiday-goers and business people annually. Approximately 9.6 million foreigners visited the country in 2008^[100], and a large percentage of those visitors are likely to have paid visits to the coastal regions. Approximately 14 million adult domestic tourists also travelled the country in 2008^[101], adding to the potential percentage visiting coastal regions. One of the top three leisure activities undertaken annually by domestic tourists is visiting the coast (the beach)^[102].

Associated leisure activities are primarily concentrated to the shoreline and shallow waters (wind surfing, surfing, para-sailing, swimming, surf-skiing, jet-skiing, in-shore boating, angling, whale watching, snorkelling, wreck and reef diving, cage diving), but a small percentage of activities take place beyond the inshore zone. This includes deep sea angling, yachting and deep sea diving.

Despite this, all marine leisure activities take place well within the 12nmi Territorial Waters zone, one notable exception being oceanic cruises.

3.5.2. Oceanic Cruises

Oceanic cruises are another form of marine leisure, operating on a global scale and on the open ocean. Travellers arrive at and depart from South African ports on a variety of cruise ships, operated by various cruise lines offering this service. Leading cruise corporations operating to and from South Africa are^[103]:

- Royal Caribbean, operating 38 ships and offering five cruise brands: Celebrity Cruises, Royal Caribbean International Cruises, Pullmantur Cruises, CDF Cruises and Azamara Cruises.
- Carnival Corporation, operating 89 ships and offering eleven cruise brands: Carnival Cruise Lines, Princess Cruises, Cunard Cruises, Seabourn Cruise Lines, Holland America Cruises, Costa Cruise, Iberocruceros Cruises, AIDA Cruises, P&O Cruises UK, P&O Cruises Australia and Ocean Village Cruises.
- NCL/STAR Cruises, operating 16 ships and offering three cruise brands: NCL Cruises, NCL America Cruises and Star Cruises.
- MSC Cruises, operating one ship, and offering one cruise brand: MSC Cruises.

The most popular cruising regions are the Caribbean, West Coast of America, Alaska, South America, the Mediterranean, Asia/Pacific regions and North and Western Europe^[104]. Southern African cruises focus predominately on visits to southern ocean islands (Mauritius, Seychelles, Reunion, St Helena), but also many World destinations^[105].

The demand has doubled within each decade, and trends indicate this will continue^[106]. This has led to a greater demand in numbers of and capacity on cruise ships. Royal Caribbean Cruises has recently started operating the

“Oasis of the Seas”, with a capacity for 5,400 passengers, more than double those carried on board previous modern liners^{[107][108]}.

Due to the nature of the industry, cruise ships operate across vast stretches of open ocean between destinations.

3.6. Aeronautical Activity

3.6.1. Military Aeronautical Operations over the Sea

The primary mandate of the SANDF is to protect the national borders, defend and protect the Republic, its territorial integrity and its people^[109]. The national maritime borders effectively stretch the length of the coastline, and extend out to sea up to the edge of the Continental Shelf zone. This marine area is therefore safeguarded by the SANDF, and utilises airborne (Air Force) and surface vessel (Navy) assets.

In addition, the SANDF is mandated to provide essential services, which includes humanitarian assistance, Search and Rescue, and national border control^[110]. Search and Rescue is provided across the entire national maritime Search and Rescue Region. This Region will be defined in detail in Chapter 4, but suffice to say it is an enormous area, effectively stretching all the way to Antarctica, and halfway to South America and Australia in the west and east respectively.

3.6.2. Commercial Flights over the Sea

From Appendix D^{[111][112][113]}, it is apparent that many major airlines, operating to and from South Africa, have routes overflying the oceans around Southern Africa. In particular, many SAA flights, as well as SA Airlink (to Madagascar), Delta Airlines, British Airways all the Far Eastern and Near Eastern airlines, and Qantas, have significant portions of their routes operating over the seas around Southern Africa, within our national maritime zones and our Search and Rescue Region. Refer to Appendix D for details of these airlines and routes.

3.6.3. Civil Recreational Flight over the Sea

The Civil Aviation Regulations Part 91^[114] provides the guidelines for, amongst others, the operation for civil and commercial aircraft over the sea. Certain restrictions and limitations are imposed, depending on the configuration of the aircraft and equipment carried on board. Civil aircraft operating over the sea are required to be equipped with life rafts and survival equipment, and, in the case of helicopters, floatation gear^[114].

Extended over-water flights are permitted, but emphasis is placed on the inclusion of life rafts amongst the survival equipment carried on board. This is particularly aimed at twin and single engine aircraft, which often falls within the “light civil recreational” category. If such aircraft are not equipped with a life raft, the maximum distance over water from the coast is 30 minutes of flight or 100 miles, whichever is reached sooner.

In essence, if a civil aircraft, commercial or recreational, is equipped with sufficient survival equipment and/or floatation gear, the distance it can fly over the sea is a function of the performance limit of the aircraft in terms of fuel capacity^{[114] [115]}.

Many civil recreational aircraft may not be equipped with all survival equipment, as specified by CAR Part 91, limiting the distance from shore to around 100 nmi. This is within the EEZ. Many others, equipped with all essential survival equipment, could potentially operate even further out to sea, well beyond the EEZ.

3.7. Recorded Maritime Incidents

3.7.1. Shipwrecks

The Southern African coastline is littered with thousands^[116] of shipwrecks, a testimony to the rough and unpredictable nature of its bordering oceans. Over 2700^[117] shipwrecks have been recorded to date around the coast. The Cape of Good Hope alone is home to more than 400^[118] shipwrecks.

3.7.2. Aeronautical Incidents

Most aeronautical incidents in and around South Africa have occurred over land, as most of the routes and the greatest percentage of flying takes place here. However, twelve notable exceptions are listed in Appendix E, all occurring in our oceans, the most infamous of which is arguably the South African Airways Helderberg incident of 1987.

3.8. Conclusion

It is evident that human activity is found across all national oceanic regions, and also well beyond our maritime borders and claims. In summary, the following activity types are prevalent per maritime claim zone:

- Coastal
 - Commercial Fishing
 - Zirconium and Titanium mining
 - Commercial Shipping
 - Naval Operations
 - Maritime Police Services
 - Marine-related leisure and recreation
 - Military Aeronautical Operations
 - Commercial Flights
 - Civil Recreational Flight
- Territorial Waters
 - Commercial Fishing
 - Diamond mining (marine)
 - Commercial Shipping

- Naval Operations
 - Maritime Police Services
 - Marine-related leisure and recreation
 - Oceanic Cruises
 - Military Aeronautical Operations
 - Commercial Flights
 - Civil Recreational Flight
- Exclusive Economic Zone
 - Commercial Fishing
 - Oil and Natural Gas mining
 - Commercial Shipping
 - Naval Operations
 - Maritime Police Services
 - Oceanic Cruises
 - Military Aeronautical Operations
 - Commercial Flights
 - Civil Recreational Flight
- Continental Shelf
 - Commercial Fishing
 - Commercial Shipping
 - Naval Operations

- Oceanic Cruises
- Military Aeronautical Operations
- Commercial Flights
- Civil Recreational Flight
- Beyond the Continental Shelf
 - Commercial Fishing
 - Commercial Shipping
 - Naval Operations
 - Oceanic Cruises
 - Military Aeronautical Operations
 - Commercial Flights

Although the greater concentration of marine-related human activity takes place within the 200nmi Exclusive Economic Zone, Search and Rescue services should be provided for to cater for all possible situations. Therefore, in a national context, maritime Search and Rescue services should be provided within, as well as beyond, our maritime claim zones, up to our defined maritime Search and Rescue Region extremities.

Chapter 4 will look in more detail at Search and Rescue in South Africa, with strong focus on our obligated Search and Rescue responsibilities.

Chapter 4

4. National Maritime Search and Rescue Responsibilities

4.1. An Introduction to Search and Rescue in South Africa

From the previous Chapters, it is clear that South Africa is host to extensive and highly active commercial shipping and fishing industries, recreational maritime activities, naval, and military and commercial aeronautical operations. All these activities take place within our often volatile, unpredictable and hostile marine environment, resulting in numerous incidents and close calls each year^[31].

South Africa borders the ocean on 41.5%^[125] of its external borders, bringing to bear certain “automatic” responsibilities concerning maritime Search and Rescue. These responsibilities rest upon every ocean-bordering state worldwide^{[126][127]}, and are not unique to South Africa.

This Chapter will examine in more detail the International trends in Search and Rescue, our obligations and responsibilities towards Search and Rescue, define our national maritime Search and Rescue Region and report on the basic composition of the national Search and Rescue Organisation.

4.1.1. International Recognition

In International context, the need for well-established, dedicated Search and Rescue capabilities was first addressed at the International Convention on Maritime Search and Rescue (the “SAR Convention”), convened in 1979 in Hamburg^{[91][128][129]}. This Convention aimed at developing an International Search and Rescue Plan, to guide and facilitate Search and Rescue establishment efforts worldwide. The Plan called, amongst others, for member States to ensure the following:

- The provisioning of adequate Search and Rescue services within their bordering coastal waters and designated maritime Search and Rescue Regions^{[91][130][131]},

- The provisioning of adequate facilities, resources, procedures and training to execute Search and Rescue in a coordinated, professional and efficient manner^{[91][130][131]};
- Encouragement of neighbouring States to enter into agreements concerning bordering Search and Rescue Regions, as well as the pooling of Search and Rescue resources^{[91][132][133]}.

In addition to these requirements, the SAR Convention set out measures and guidelines for the establishment of Rescue Coordination Centres, Rescue Sub-Centres and automated ship reporting systems^{[91][134][135][136][137]}.

Following prolonged use, the Plan, as set out by the 1979 SAR Convention, was significantly amended, and finally adopted in its new form in 1998 by the International Maritime Organisation (IMO)^[91]. In addition to the original requirements and stipulations, the amended 1998 Plan:

- Clarified Government responsibilities^[91];
- Placed greater emphasis on regional cooperation^[91]; and
- Aimed at harmonising Maritime and Aeronautical Search and Rescue operations performed over the sea^[91].

4.1.2. International Search and Rescue Standards

The following are some of the Internationally recognised and accepted Search and Rescue terminology and standards as set out by the IMO, ICAO and other organisations:

Definition of Search and Rescue: The term “Search and Rescue” is the process of searching for and providing rescue services to persons who are believed to be in imminent danger of losing their lives^[162].

Definition of an Aeronautical Incident over the Sea: It is broadly recognised that an aeronautical incident over the sea becomes, and is duly treated as, a maritime incident^[163].

Primary Need: The primary need is for the rapid location and rescuing of survivors of accidents^[164].

Search and Rescue Region: States are to accept the moral responsibility for the Search and Rescue Regions established within their Maritime area^{[91][165]}.

Search and Rescue Region: States are required to provide Search and Rescue services within their territories and over their portions of the High Seas and within their Coastal Waters^{[166][167]}.

Government Responsibility: The Search and Rescue function is a Government responsibility following on the acceptance of the obligations bestowed upon it through membership to ICAO, the International Convention on Maritime Search and Rescue, and SOLAS^[162].

Government Responsibility: The Safety of Life at Sea (SOLAS) Convention requires that “each Contracting Government should undertake to ensure that necessary arrangements are made for distress communication and co-ordination in their area of responsibility and for the rescue of persons in distress at sea around its coasts^[91].”

State Responsibility: The implementation of an efficient Search and Rescue system is a fundamental obligation of all ICAO and IMO Contracting States^{[168][169][170][247]}.

State Responsibility: States are required to establish and formulate the basic elements of SAR services, including the definition of the legal framework, the assignment of a responsible Search and Rescue Authority, the establishment and organising of Search and Rescue resources, adequate communications infrastructure and facilities, the setting up of operational functions, setting up of domestic and international cooperative relationships, and a training basis^{[171][172]}.

State Responsibility: States are required to set up Rescue Coordination Centres (RCC's) and Rescue Sub-centres (RSC's) to coordinate National and joint Search and Rescue efforts^[173].

Rescue Coordination Centres: Rescue Coordination Centres are to be established to coordinate resources to perform searching and effect a rescue operation in a particular SRR^{[174][175][176]}.

Rescue Coordination Centres: The prompt receipt of information by a Rescue Coordination Centre is vital to ensure effective evaluation and immediate decision-making on the best course of action, and timely activation of rescue assets to enable location, support and rescuing of persons in distress, in the shortest possible time^[164].

International Impact: National Search and Rescue services and methods are considered to form an integral part of the Worldwide SAR System^[177].

Harmonised Operations: The harmonisation of Aeronautical and Maritime Search and Rescue is a requirement for effective and efficient SAR operations over the seas^{[178][179]}.

Search and Rescue Resources: Rescue Coordination Centres are to assist each other in the provision of personnel, aircraft, vessels, equipment and other resources, as and when required^{[180][181]}.

Search and Rescue Resources: Nations shall use all available means, methods, resources, facilities and other Search and Rescue units to provide assistance during a search and during the rescue effort^[182].

Search and Rescue Resources: Search and Rescue units shall be provided with the necessary equipment to enable efficient and effective execution of all tasks^{[183][184][185][186]}.

Search Termination: Search and Rescue operations are to continue until all reasonable hope of rescuing survivors has passed^{[187][188][189]}.

Search Termination: The suspension of a search during a SAR operation shall only be considered once all assigned areas have been thoroughly searched, all probable locations have been investigated and all means of obtaining information concerning the whereabouts of those in distress have been exhausted^[189].

4.1.3. National Recognition

In line with these requirements and standards, and as a member nation to the SAR Convention, South Africa has agreed to provide effective, efficient and professional Search and Rescue services within its designated Search and Rescue Region^{[126][127]}.

4.2. South African Search and Rescue Organisation

In answer to South Africa's moral and humanitarian obligation to provide an effective, efficient, well organised and professional Search and Rescue service, and in consideration of Search and Rescue standards being observed worldwide, the South African Search and Rescue Organisation (SASAR) was promulgated in 1979^{[138][139]}. The origins of SASAR actually stretch as far back as 1958^{[138][139]} when the Permanent Committee for Search and Rescue was established. In 1961^{[138][139]}, the Committee changed its name to the Permanent Executive Committee for Search and Rescue (PECSAR).

The PECSAR National SAR Manual was developed the same year^[139]. In 1979, following the SAR Convention, PECSAR underwent a further name change and became SASAR^{[138][139]}. The revised SASAR Manual came into effect in 1993^[139].

4.2.1. SASAR Objectives

According to the South African Maritime and Aeronautical Search and Rescue Bill, the objective^[140] of SASAR is "to ensure a co-ordinated and effective maritime and aeronautical search and rescue service within the South African search and rescue regions." The Bill continues to say that SASAR executives are to "ensure that search and rescue operations are conducted in accordance with laid down standards and recommended practices as reflected in the SASAR Manual and as considered the norm in terms of international agreements^[141]."

Other statements concerning SASAR, as contained in the Bill, are^[142] that "SASAR must within its means and capabilities co-ordinate its resources to search for ... survivors of aircraft crashes ... vessels in distress ... survivors of

maritime accidents or incidents ... survivors of any military aircraft or vessel accident or incident...” The Bill also states that^[143] “SASAR must perform its functions in a manner which promotes efficient, economic and effective use of all resources.”

In the SASAR Constitution (preamble) it states^[144] that Government is “Conscious of South Africa’s obligations in terms of the International Convention on Maritime Search and Rescue, 1979 and Annex 12 to the Convention on International Civil Aviation, 1944 and other relevant Conventions”, while also^[144] being “Conscious of an established international practice based on traditional humanitarian obligations to assist any aircraft, vessel or person in distress.”

The SASAR Constitution provides the same objective^[145] for SASAR as the SAR Bill, while adding other objectives, including^[146] “To minimise time spent searching for persons in distress by using technology, research and development, education, regulation and enforcement.”

The SASAR National SAR Manual (draft), Chapter 1, states that the National Search and Rescue organisation was established^[147] “to provide South Africa with a world-renowned Search and Rescue capability or function.”

To summarise, therefore, it is clear that as a nation, we are expected to:

- Ensure that we have in place a co-ordinated, efficient and effective maritime and aeronautical Search and Rescue service, on a par with International norms and standards;
- Co-ordinate resources to search for survivors of any and all commercial, recreational and military aircraft accidents and vessels in distress within our national Search and Rescue Region, in other words, survivors of all maritime accidents or incidents;
- Conduct Search and Rescue operations in accordance with laid down standards and recommended practices;

- Conduct Search and Rescue operations in a manner considered the norm in terms of International standards;
- Conduct such operations while minimising time spent searching for persons in distress by using technology, research and development, education, regulation and enforcement.

4.3. Additional International and Regional Maritime Agreements

4.3.1. International Agreements and Memberships

As mentioned in the aforementioned section, South Africa has agreed to provide World-class Search and Rescue services, in accordance with the requirements set out in the 1979 and 1998 Plans drafted by the SAR Convention. In addition to the SAR Convention, South Africa is a member of the following Search and Rescue- or Maritime-related Organisations, Conventions, Committees and Bodies, incurring similar levels of responsibility:

- International Maritime Organisation (IMO) ^{[91][148][149]} (Member State, since 1995)
- International Civil Aviation Organisation (ICAO) ^{[149][150]} (Contracting State)
- United Nations Convention on the Law of the Seas (UNCLOS) ^[151] (Subscriber, treaty ratified 23 December 1997)
- Convention on Safety of Life at Sea (SOLAS) ^{[152][153]} (Signatory, treaty ratified under auspices of the IMO)
- Standing Maritime Committee (SMC) ^{[154][155]} (Member)
- International Hydrographic Organisation (IHO) ^[156] (Member State)

South Africa is morally, humanitarily and, in certain cases legally, bound and obliged to observe the guidelines, strategies, plans, treaties and laws, for which it is a co-signatory, subscriber or member.

4.3.2. Regional Cooperation

The SAR Convention places great emphasis on regional cooperation^{[132][133]}.

In a regional context, South Africa is a member nation of:

- African Union (AU)^[157] (Member)
- Southern African Development Community (SADC)^[158] (Member)
- Inter-State Defence and Security Committee (ISDSC)^[159] (Member)
- Africa Economic Community (AEC)^[160] (Member since 1997)

In terms of cooperative Search and Rescue, the SADC Search and Rescue Region coastal border stretches from the northern border of the Democratic Republic of Congo on the west coast around the southern tip of Africa to the northern border of Tanzania on the east coast. It also includes Madagascar, Mauritius and Seychelles. The combined SADC coastline length is in excess of 15,300km^[1] and presents a combined Exclusive Economic Zone of 7,572,680km^{2[161][247]}. Although this thesis focuses on the national (South African) Search and Rescue Region, and associated responsibilities and capabilities, the “regionally cooperative” Search and Rescue responsibilities cannot be disregarded.

4.4. National Rescue Centres

In alignment with the International requirements for Search and Rescue, South Africa has established a number of Rescue Centres to coordinate Search and Rescue efforts.

4.4.1. National Maritime Rescue Coordination Centre (MRCC)

The national Maritime Rescue Coordination Centre (MRCC) is situated in Cape Town^{[91][190]}. This MRCC also acts as a regional MRCC and training centre for Angola, the Comoros, Madagascar, Mozambique and Namibia^[91]. The national MRCC was officially opened on 16 January 2007 by Efthimios E. Mitropoulos, Secretary-General of the International Maritime Organization^[91].

4.4.2. National Aeronautical Rescue Coordination Centre (ARCC)

The national Aeronautical Rescue Coordination Centre (ARCC) is situated at OR Tambo International Airport, Johannesburg^[191].

4.4.3. National Rescue Sub-Centres

The SASAR national SAR Manual (draft), Chapter 2, provides details concerning the location of the seven permanent Rescue Sub-Centres (RSC's), and associated Secondary Rescue Sub-Centres (Secondary RSC's)^[192]. In the event of a maritime emergency, the MRCC may delegate responsibility to the Rescue Sub-Centre in the sub-region affected, to coordinate the Search and Rescue effort. Appendix F provides a summary of the National RSC's and their associated Secondary RSC's.

4.5. National Maritime Search and Rescue Region

The previous paragraphs have highlighted South Africa's responsibilities and willingness towards Search and Rescue. Furthermore, it is evident that South Africa wants to be ranked among the foremost nations as far as Search and Rescue is concerned, providing effective, efficient, well-organised and professional services within its allocated Search and Rescue Region.

4.5.1 Search and Rescue Region Allotment

Following the 1979 International Convention on Maritime Search and Rescue, the IMO Maritime Safety Committee divided the entire World oceanographic surface into thirteen^[194] primary Search and Rescue areas. Within each primary area, countries bordering the ocean are required and encouraged to perform Search and Rescue duties within a delimited and allotted Search and Rescue Region (SRR). The 1998 amendment of the SAR Convention further emphasised the relevance of Search and Rescue Regions, and associated national responsibilities. The amendment clearly stipulates that once a Search and Rescue Region has been defined, neighbouring States accept responsibility for providing Search and Rescue services within that Region^{[194][195][196]}.

The geographic location of the State in question determines the size and borders of the allotted Region. Additionally, the national Search and Rescue Region is divided into an Aeronautical Area, defined and controlled by the International Civil Aviation Organisation (ICAO)^{[191][195][196][197]}, and a Maritime Area, defined and controlled by the International Maritime Organisation (IMO)^{[190][195][196][197]}. The Maritime Area of the Search and Rescue Region is restricted to the ocean, while the Aeronautical Area covers the entire overland part, as well as parts over the ocean^[198].

In most cases, the Maritime Area and Aeronautical Area over the sea overlaps (the amount of overlap is dependent on the level of cooperation decided upon between ICAO and the IMO, as well as other political considerations and agreements between neighbouring ocean-bordering States). This is true for our national Search and Rescue Region as well. For the purposes of this thesis, the “maritime Search and Rescue Region” is the summation of both the Maritime and Aeronautical Areas over the sea. This equates into a combined national maritime Search and Rescue Region with an oceanographic area of 8,051,392.6nmi² (27,615,503.7km²)^[40].

The borders of the summed national maritime Search and Rescue Region are as follows:

4.5.2. Coastal Demarcation

The Coastal Demarcation is from the border between Angola and Namibia in the west (17°51’S-latitude), along the coast to the border between South Africa and Mozambique in the east (26°51’S-latitude)^{[40][165][197][199]}.

4.5.3. Northern Demarcation

The Northern Demarcation is the 117°51’S-latitude in the west, and the 26°51’S-latitude in the east. In the east, the Northern Demarcation steps down to the 30°S-latitude when passing the 40°E-longitude, and steps down again to the 50°S-latitude when passing the 57°E-longitude^{[40][165][197][199]}.

4.5.4. Southern Demarcation

The Southern Demarcation is the Antarctic Coastline^{[40][165][197][199]}.

4.5.5. Western Demarcation

The Western Demarcation is the 10°W-longitude^{[40][165][197][199]}.

4.5.6. Eastern Demarcation

The Eastern Demarcation is the 75°E-longitude^{[40][165][197][199]}.

This is roughly halfway to South America on the west, halfway to Australia on the east, and all the way to Antarctica in the south.

Figure 4.1 provides a graphical representation^{[197][198]} of the national Search and Rescue Region, including the Maritime and Aeronautical Areas.

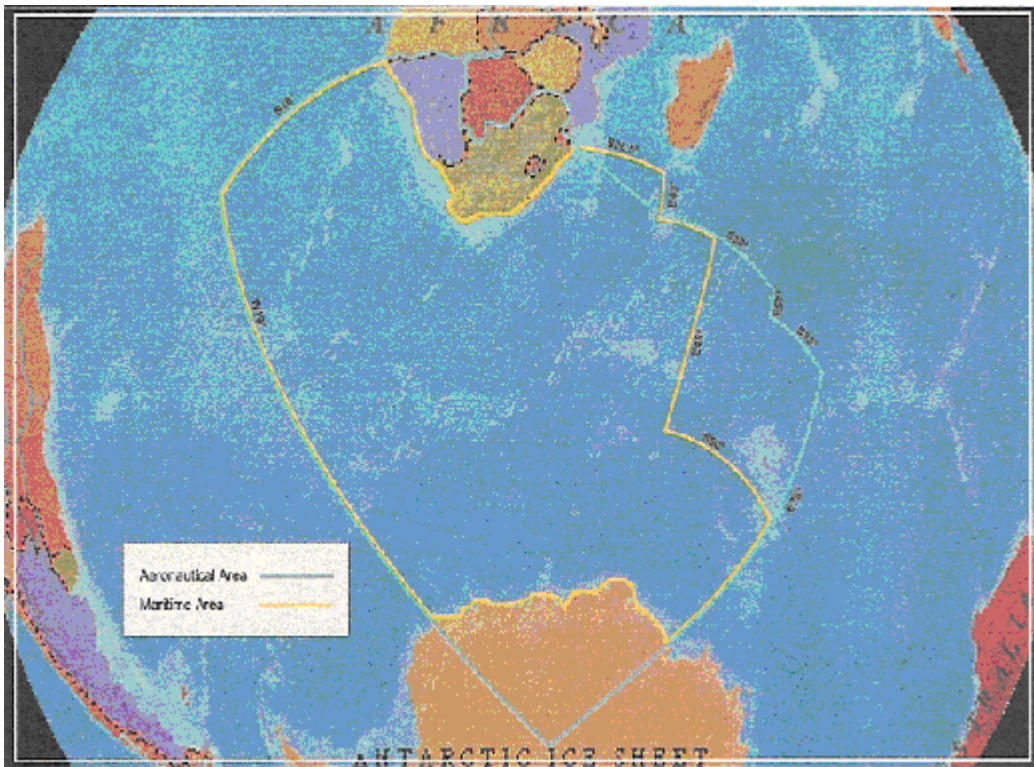


Figure 4.1: South African Search and Rescue Region^[198]

Global maritime Search and Rescue Regions are portrayed in Figure 4.2.

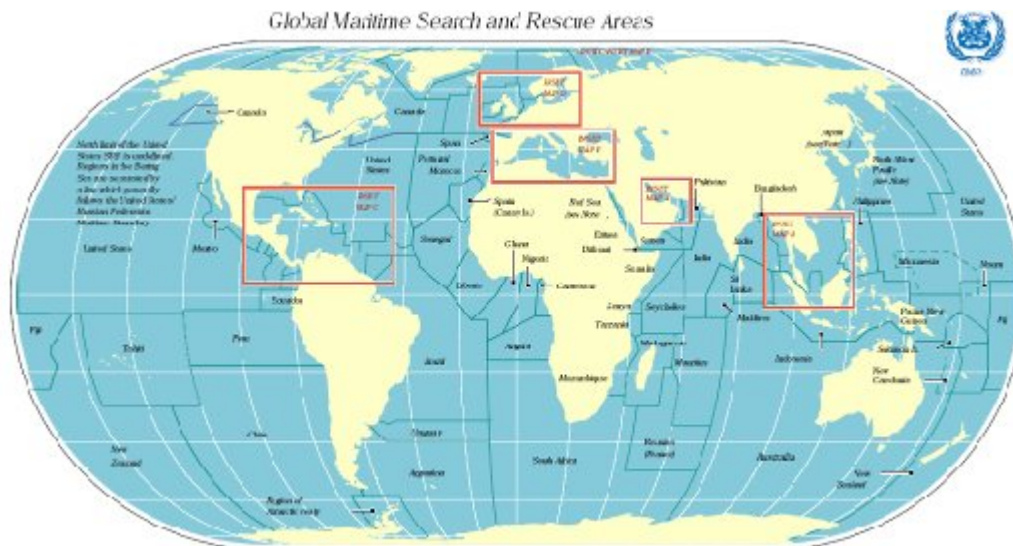
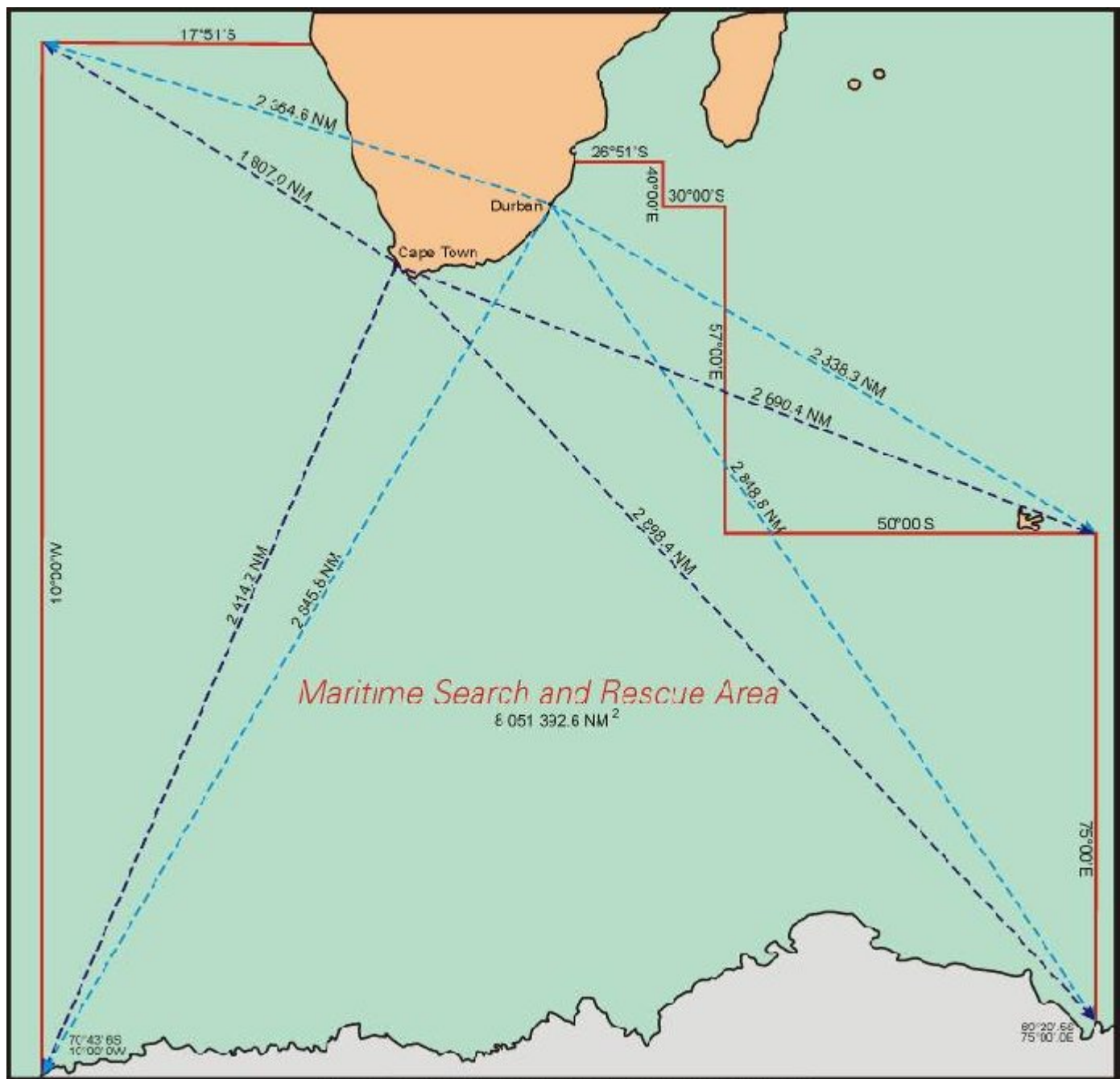


Figure 4.2: Global Maritime Search and Rescue Regions^[200]

From the Figure 4.2^[200] it is evident that South Africa has been allotted one of the five largest maritime Search and Rescue Regions in the World, with only Australia, New Zealand, Chile and the United States having larger or similar sized Regions.

Figure 4.3 provides a graphical representation of the summed national maritime Search and Rescue Region, highlighting a number of key elements. The map includes distances from two main ports to the outermost extremities of the national maritime Search and Rescue Region. The distances calculated take into account the curvature of the Earth, and are presented in Nautical Miles^[40].



Prepared at the SANavy Hydrographic Office, 21 July 2010.

Figure 4.3: Summed National Maritime Search and Rescue Region^[40]

4.5.7. Major Distances

From Figure 4.3^[40]:

The furthest point from Cape Town is to the 69°20'.5S//75°E intersection, a distance of 2,898.4nmi.

The furthest point from Durban is also to the 69°20'.5S//75°E intersection, a distance of 2,848.8nmi.

4.6. National Organisations Equipped to Perform Maritime Search and Rescue Activities

Organisations like SASAR and the Maritime Rescue Coordination Centre are actively involved in Search and Rescue, but are themselves not equipped to physically carry out these activities. These Organisations typically generate and enforce policy, plans and guidelines, or perform a coordinating function^[201]. There are, however, a number of Organisations who are equipped to interpret these policies, plans and guidelines and carry them through into practicality, and actively partake in Search and Rescue activities when called upon.

Such Organisations are equipped with specialised assets (vehicles, equipment, skilled personnel, facilities and infrastructure, etc) to enable them to carry out and fulfil the required tasks.

This section provides a shortlist of the major Organisations in South Africa equipped to perform maritime Search and Rescue activities.

4.6.1. The National Sea Rescue Institute (NSRI)

The National Sea Rescue Institute (NSRI) was promulgated on 12 June 1967^[202]. It remains one of the foremost Organisations involved with maritime Search and Rescue. The following statistics^[203] provide an overview of the scale of efforts and accomplishments, calculated from date of inception to the publication of this thesis:

Sea rescue Operations performed: 14,540

Persons assisted: 26,023

4.6.2. South African Police Services (SAPS)

The SA Police Service roles include the policing and safeguarding of our national borders against crime. This includes the maritime border and maritime zones, up to and including the Exclusive Economic Zone^[98]. The police assist the South African National Defence Force and NSRI in providing rescue services within these zones^[204]. This includes the provision of aircraft, boats and personnel^[205].

4.6.3. South African National Defence Force (SANDF)

The primary mandate of the South African National Defence Force (SANDF) is to protect the national borders, defend and protect the Republic, its territorial integrity and its people^[109]. In addition, the SANDF is mandated to provide essential services, which includes humanitarian assistance, Search and Rescue, and national border control^[110]. The SANDF is regarded as the primary and most critical national Search and Rescue asset^[206]. This includes the provision of ships and aircraft, crews and personnel, communications infrastructure, bases, facilities and special equipment^[207]. The primary Arms of Service providing maritime Search and Rescue services are the SA Navy and the SA Air Force.

4.6.3.1. SA Navy

The role of the SA Navy involves the safeguarding, patrolling, policing and protecting of our national maritime borders and zones. These include the Territorial-, Contiguous-, Exclusive Economic- and Continental Shelf zones of the country, and includes the Prince Edward/Marion Island Group^[45]. Other specialised roles include Search and Rescue^[45].

This requires a Naval Fleet capable of operating anywhere within our sovereign waters, and beyond. The Search and Rescue role alone necessitates the Navy to operate the entire national Search and Rescue Region, which, according to the Navy, covers an area of more than 17.2

million km² [45]. The SA Navy currently owns no aircraft of its own, but utilises the services of the SA Air Force for maritime air support.

4.6.3.2. SA Air Force

In addition to protecting the sovereignty of the nation and safeguarding our borders, the SA Air Force is to provide essential services (as for the SA navy). This includes the provision of Search and Rescue services across the entire national maritime Search and Rescue Region.

4.6.4. National Ports Authority (NPA)

Although the National Ports Authority (NPA) core business is not Search and Rescue, it plays an important role in this regard. This includes ensuring that Port Control centres perform their duties as Rescue Sub-Centres and Secondary Rescue Sub-Centres; ensuring that all light houses act as alerting posts; and providing essential communications during Search and Rescue activities^[208]. NPA do operate three light helicopters for transporting of personnel to and from ships, primarily in the Harbour Pilot Shuttle (HPS) service^{[209][210]}. These assets are employed for maritime Search and Rescue services, should the need arise.

4.6.5. Titan Helicopter Group

Titan Helicopter Group is a global initiative, with a regional head office in Cape Town, and operating bases in Cape Town docks and George. Operations include oil rig support, heli-ship services, diamond production vessel support, marine pilot services, surveys, ad-hoc charters and Rescue Services^[211]. Titan Helicopters places a strong focus on Search and Rescue and Emergency Medical Services, providing well-trained crews and specialist rotorcraft assets^[212].

4.7 Conclusion

It is evident that South Africa is legally and morally bound to provide a World class Search and Rescue service; this includes its maritime regions. South Africa has pledged to provide an effective, efficient, well-organised and professional Search and Rescue service within the full scope of its Search

and Rescue Regions. The South African Search and Rescue Organisation has been created to effect and coordinate this service, along with several Organisations capable of providing specialised assets to the cause.

The South African maritime Search and Rescue Region is one of the five largest worldwide. Surface and airborne Search and Rescue assets are required to be able to operate effectively and efficiently to the extremities of this region, a distance of more than 2800nmi from the nearest major port or airfield. Although assets are grouped into classes, and thus not all assets are required to be able to meet this demand, at least one such an asset should be available to fulfil this requirement.

The next chapter will examine in more detail the minimum performance requirements for a Search and Rescue asset required to operate effectively up to the national maritime Search and Rescue Region extremities.

Chapter 5

5. Quantifying the Key Performance Requirements

The previous Chapter determined the necessity for Search and Rescue assets to be able to operate effectively within the entire South African maritime Search and Rescue Region, up to and including the Region extremities^{[143][176][182][213][214][215][216][217][218]}. A comparative study will be performed in later Chapters to determine whether any existing Search and Rescue assets currently meet this requirement. As a precursor to this comparative study, the key performance requirements for such an asset need to be determined. This Chapter will examine the factors influencing these key performance requirements, and quantify them.

5.1. Generic Requirements for Maritime Search and Rescue Aircraft

5.1.1. *Airborne Assets: Typical Advantages*

Aircraft are essential assets to any Search and Rescue mission. Aircraft can be either fixed wing, rotary wing (helicopters), or a combination, typically tilt-rotors. Aircraft possess unique design features enabling them to perform certain tasks more effectively than surface vessels (ships and boats). Typical advantages offered by aircraft employed for Search and Rescue operations include^{[242][243][244][247][248][249]}.

- The ability to cover great distances and large areas in a short time;
- The ability to carry and deliver stores (rescue supplies, dinghies, markers, etc) with high accuracy to those in distress;
- The ability to act as an airborne command post or communications relay during the operation;
- The ability to detect objects beyond the natural horizon for ships or vehicles (early detection).

5.1.2 Aircraft Configuration, Specialisation and Application

Aircraft are often specialised, specifically configured or purpose-designed for specific roles, tasks or missions. As a result, aircraft rarely have equal abilities; some are designed to operate over specific ranges (either long or short); some are designed with Vertical Take-off and Landing capabilities; some have the ability to stay airborne for many hours (endurance and persistence); others are designed for high speed. The same holds true for Search and Rescue; aircraft are chosen and applied within the Search and Rescue environment to exploit inherent design characteristics to the maximum.

5.2. Factors Influencing the Key Performance Requirements

Many factors influence the choice of performance characteristics for aircraft. The following are typical factors having a direct influence on the key performance requirements for aircraft employed in Search and Rescue:

- Size of the Search Area (range, endurance, persistence);
- National oceanographic characteristics (hostility, visibility, average sea state, etc);
- Marine weather patterns and climatic conditions (surface air temperatures, wind speed, precipitation levels, etc);
- General activity involving humans across the Search and Rescue Region (shipping, leisure, mining, aeronautical, etc);
- Level of interaction and cooperation between neighbouring States (potential extension of Search Area).

As a result, each nation's requirements will be unique to some extent.

5.3. Key Performance Requirements

5.3.1. Generic Requirements

Rescue missions imply that people are in imminent danger of losing their lives. As a result, time is always of the essence, as those in distress need to

be located and rescued in the shortest time possible. Additionally, it is essential that search parties remain in the search area for as long as possible, and cover as large an area as possible, implying endurance and persistence. These basic generic requirements will always be associated with Search and Rescue assets, regardless of specific national requirements. More specifically, all Search and Rescue assets feature the following key performance requirements^{[243][244][248]}.

- Speed: Speed is essential in order to reach the search area or rescue scene in the shortest time possible. The speed of the asset should therefore be as high as possible.
- Endurance: Endurance is essential to afford assets to stay in the search area and prolong searches for as long as possible. The endurance and persistence of the asset should therefore be as long as possible.
- Range: Depending on the extent and limits of the search area, reach, or range, might also be of vital importance. In consideration of the vastness of the national Search and Rescue Region, and the great distances to its extremities, the reach and range capability of the asset should be as great as possible.

5.3.2. Speed Quantification

Hypothermia sets in rapidly in cold water, and a large portion of the national maritime Search and Rescue Region is replete with icy water. The average annual sea surface temperatures around Southern Africa ranges between 16 and 26°C^{[12][22][23]}, while the average annual sea surface temperature around Marion Island is between 3 and 10°C^{[27][30]}, and this is only halfway to the Antarctic.

Hypothermia Charts indicate that, for water at a temperature of 50 to 60 degrees Fahrenheit (10 to 15.5°C), exhaustion or unconsciousness occurs in 1 to 2 hours, while expected time of survival is between 1 and 6 hours^[237]. Survival times rapidly diminish below 10°C. In consideration of these facts, it

is therefore imperative that Search and Rescue assets be capable of reaching the specified search area within 6 hours at most.

5.3.3. Search Time and Endurance Quantification

Before attempting to quantify endurance, the Search Time needs to be quantified. The Search Time is the time the asset needs to stay in the search area, looking for survivors. This figure is not specifically defined by major Search and Rescue Organisations, but remains important for this study, as it potentially constitutes a considerable percentage of the overall endurance of the Search and Rescue asset.

The South African Air Force Directorate Air Capability and Plans has specified a four-hour Search Time (loiter) requirement for SAAF Search and Rescue operations^[238], while operating at the maximum specified range. Therefore, as a benchmark, and for the purposes of this thesis, the Search Time is quantified as four hours minimum, at the required search range.

The total endurance is therefore quantified as the time required to reach the search area, plus four hours search time, plus the time required to return to base, plus an additional hour to cater for emergencies.

5.3.4. Range Quantification

The range requirement of the asset is dependent on the extent and limits of the search area, and projected location of those in distress. The total range is quantified as the distance to the search location, plus the distance travelled during the four hour loiter, plus the distance travelled back to base, plus the distance travelled in one hour (emergencies), all at maximum cruise speed.

The primary aim of this thesis is the specification of an airborne asset useful at the Search and Rescue Region extremities^[248] (i.e. maximum search location). However, for completeness, six search locations will be considered, and the speed, endurance and total range will be calculated for each of these locations. The six search locations are the following:

- Limit of the Territorial Waters (12nmi)

- Limit of the Contiguous and Maritime Cultural Zone (24nmi)
- Limit of the Exclusive Economic Zone (200nmi)
- Limit of the Continental Shelf (350nmi)
- Limit of the Marion Island Rim (1770nmi)
- Limit of the national maritime Search and Rescue Region (search extremities) (2800nmi).

5.4. Quantifying the Key Performance Requirements

Appendix I contains the detail calculations and train of thought for each of the six search locations identified above.

5.5. Key Performance Requirement Summary

In summary, the key performance requirement minimums (speed, range and endurance) for aircraft performing Search and Rescue activities to the limits of each of the six search locations, as defined above, are as follows:

5.5.1. Territorial Waters

- Speed: 50kn
- Range: 274nmi
- Endurance: 5h 29m

5.5.2. Contiguous and Maritime Cultural Zone

- Speed: 50kn
- Range: 298nmi
- Endurance: 5h 58m

5.5.3. Exclusive Economic Zone

- Speed: 50kn

- Range: 650nmi
- Endurance: 13h

5.5.4. *Continental Shelf*

- Speed: 58.3kn
- Range: 1166.4nmi
- Endurance: 17h

5.5.5. *Marion Island Rim*

- Speed: 295kn
- Range: 4425nmi
- Endurance: 17h

5.5.6. *Search Extremities*

- Speed: 466.7kn
- Range: 7933.5nmi
- Endurance: 17h

5.6. Conclusion

The key performance requirements, i.e. speed, range and endurance, for maritime Search and Rescue aircraft operating at the limits of six pre-defined search locations, have been quantified. These key performance requirement figures will be used in a later chapter to compare with performance figures of existing maritime Search and Rescue aircraft, and to determine deficits and shortcomings, if any.

Chapter 6

6. Determining the Special SAR Equipment Requirement

Chapter 5 identified and quantified the key performance requirements for a Search and Rescue aircraft operating over the entire national maritime Search and Rescue Region. In addition, due to the nature of the tasks to be performed, Search and Rescue aircraft are highly specialised vehicles, and are ideally equipped with special Search and Rescue equipment. The technological enhancements provided by special SAR equipment assist search parties in locating survivors in poor weather conditions, high sea states, over long distances or in the dark. Although the use of such technology is no guarantee for success, the addition of such equipment provides search parties with essential tools to help them and to greatly enhance the chances of mission success^[10]. Without the added benefit of technology, search parties are required to rely only on natural or binocular-enhanced eye-sight. This could lead to longer search times, putting survivors at risk of not being located in time, or at all, resulting in a potentially failed operation.

This chapter examines the special SAR equipment available and determines the minimum equipment configuration required to conduct effective maritime Search and Rescue operations.

6.1. Special SAR Equipment

6.1.1. Search Equipment

Primary special Search equipment available for maritime Search and Rescue aircraft includes Forward Looking Infra Red sensors, Electro-Optical & Infra Red sensors, Maritime Search Radar and Search and Rescue Direction Finders^{[225][226][247][248]}.

6.1.1.1. Forward Looking Infra Red (FLIR) Sensor

A FLIR sensor operates in the Infrared (IR) bandwidth of the light spectrum. It is used to detect and identify warm objects under low light conditions^[222], and is therefore ideal and essential for locating objects or persons at night or in bad weather conditions, offering low visibility. An IR sensor can distinguish

between cold and warm objects, and is therefore helpful in detecting survivors (warm bodies) in the colder surrounding ocean^[222].

An EO/IR sensor turret incorporates an IR thermal sensor and a high resolution optical colour camera^[223]. Both the IR sensor and colour camera are housed in the same turret, and can be coupled with additional laser payloads. Once radar has detected and located an object, the sensor turret can be slaved to the radar^{[241][249]}, and, depending on range, light and environmental conditions, either the IR, or the optical camera, or both, can be directed and zoomed onto the object for detail identification.

For the purposes of this thesis, the optical sensor will be referred to as “FLIR”, and incorporates both an IR sensor, a high resolution optical colour camera and laser payloads.

6.1.1.2. Maritime Search Radar (MSR)

Maritime Search- or Surveillance Radar^[246] is high resolution radar designed to detect objects as small as periscopes, humans and small dinghies in rough sea conditions. Complex algorithms and powerful processing techniques are employed to enable these radars to distinguish between wave clutter and physical objects^[224]. Radar has far superior detection ranges over FLIR or EO/IR sensors, and therefore remains the primary search, locate and detect sensor. Depending on the system design, once an object has been detected with radar, the FLIR or EO/IR sensor can be slaved^{[224][241][249]} to it and be directed onto the object for detail identification.

6.1.1.3. Search and Rescue Direction Finder (SAR DF)

A Search and Rescue Direction Finder (SAR DF) is designed to intercept and pinpoint emergency beacon signals, emanating from vessels, aircraft or individuals in distress^{[225][226]}. For a SAR DF to be effective, the vessel, aircraft or individual being searched for must be in possession of an operative Emergency Position Indicator Radio Beacon (EPIRB), Emergency Locator Transmitter (ELT) or a Personal Locator Beacon (PLB)^{[225][226][227]}. EPIRBs are buoyant and are carried aboard ships, ELTs are carried aboard aircraft, and

PLBs are usually man-portable and employed predominantly for land-based applications^{[226][227][228]}.

Emergency beacons operate on specific frequencies. Prior to 1 February 2009, emergency beacons operated on 121.5 MHz (or 243 MHz for military applications) VHF and 406 MHz UHF^{[226][227]}. Due to accuracy and reliability issues, and the fact that no GPS or other digital data can be sent, satellite detection of the 121.5 and 243 MHz beacons have been discontinued^{[226][227][228]}. These frequencies are now only used for short-range location during SAR operations. Satellite detection of emergency signals has now been superseded by the 406 MHz beacon^{[226][227]}. For maritime applications, distress signals can also be transmitted on dedicated maritime channels, operating over the frequency range 156 – 162.025 MHz^{[225][226]}.

406 MHz signals are intercepted by COSPAS-SARSAT satellites, transmitted to satellite ground receivers, and relayed to rescue centres. By using the original GPS position provided by the satellites as a starting point, search aircraft or vessels equipped with SAR DF can home in on the signal and locate survivors^[228].

A modern SAR DF should be able to intercept all emergency locator transmitter frequencies.

6.1.1.4. Search Light

Although not as effective as an EO/IR or FLIR sensor, a powerful search light^[248] is valuable in low light conditions, particularly at very close ranges during the actual rescue. It also provides light to survivors and rescuers, and to those interacting with them, during the rescue.

6.1.2. Rescue Equipment

Complementing Search equipment is Rescue equipment. In terms of maritime Search and Rescue, Search and Rescue aircraft are primarily used in the “Search” role, to locate survivors; actual rescuing is primarily performed by surface vessels. Rotary wing and tilt-rotor aircraft are a notable exception. This aside, all maritime Search and Rescue aircraft should be equipped with

certain Rescue equipment as a minimum, capable of assisting survivors at sea until additional aid arrives.

Primary special Rescue equipment employed on maritime Search and Rescue aircraft includes Satellite Communication, Location Markers, Aid Life Supply Canisters and Rescue Hoists^{[227][228][235][247][248]}.

6.1.2.1. Satellite Communication (SATCOM)

Communication is vital during the Search and Rescue operation, but even more so during the actual rescue effort. Maritime Search and Rescue aircraft operate over an environment devoid of repeater antennas to cover the potentially vast distances. As long as there is satellite coverage, SATCOM will provide maritime Search and Rescue aircraft unlimited communications capability (voice and data), irrespective the location or range from base^{[229][230][231]}.

Broadband SATCOM provides the capability to not only transfer voice and low volume data, but medium- to high definition, or near-real-time, picture and video as well^[248]. SATCOM is also particularly useful for the relaying of the location of survivors to surface vessels or other aircraft, and is essential for seamless communication between Search and Rescue parties during the search effort.

6.1.2.2. Marine Location Markers

Marine Location Markers typically^[234] include smoke markers and/or smoke markers incorporating flares, and are used to mark the physical location of survivors at sea. Visible over great distances, the markers provide a visual homing cue for surface vessels and aircraft tasked to perform the rescue. New types incorporate a 406 MHz emergency beacon, or employ only the beacon and exclude the smoke generation component^[234].

6.1.2.3. Aid Life Supply Canisters

Aid Life Supply Canisters are dropped near to survivors at sea and contain life support gear. Typical gear included in Aid Life Supply Canisters are^[235]:

- Life Raft
- Life Vest
- Thermal Blanket
- Medical Supplies
- Locator Transmitter
- Dry clothing and towel
- Food supplies

6.1.2.4. *Rescue Hoist*

A rescue hoist is only usable on an aircraft type capable of entering into a hover. Many Search and Rescue helicopters are equipped with a rescue hoist, or can be easily configured with one. The hoist is used during the rescue operation to transfer survivors to the rescue vehicle.

6.2. Special SAR Equipment: Minimum Equipment Configuration

6.2.1 *Minimum Search Equipment*

As a minimum, and as deduced for this thesis, the following Search equipment should form part of the standard fitment for an aircraft deployed for maritime Search and Rescue operations:

- Forward-looking Infrared (FLIR) sensor
- Maritime Search Radar (MSR)
- Search and Rescue Direction Finder (SAR DF)

6.2.2. *Minimum Rescue Equipment*

As a minimum, and as deduced for this thesis, the following Rescue equipment should form part of the standard fitment for an aircraft deployed for maritime Search and Rescue operations:

- Satellite Communication (SATCOM)
- Marine Location Markers (MLM)
- Aid Life Supply Canisters (ALSC)

6.3. Conclusion

The minimum special maritime Search and Rescue equipment configuration has been defined for an aircraft to be effective during maritime Search and Rescue operations. This configuration will be used in a later chapter to compare with the equipment configuration of existing maritime Search and Rescue aircraft, and to determine deficits and shortcomings, if any.

Chapter 7

7. Maritime Search and Rescue Aircraft: Domestic

Aircraft form an essential part of any Search and Rescue operation, particularly when those in distress are located in a remote or hostile environment. This chapter examines which aircraft types are currently available in South Africa, and are deployable for maritime Search and Rescue tasks. Special attention will be given to their key performance figures, as well as special SAR equipment configurations.

7.1. Domestic Aircraft Types Currently Available for Maritime Search and Rescue

The SASAR Assets Manual contains details of all domestically available assets (aircraft, ships, etc) deployable for Search and Rescue operations. Unfortunately, SASAR was unable to provide an up-to-date version of the SASAR Assets Manual before the completion of this thesis. Asset availability was therefore confirmed verbally with personnel at SASAR and from information provided by Operators. SASAR did confirm that, although they do make use of civilian operators to supply assets, their foremost supplier for aircraft for SAR operations remains the South African Air Force. Other potential suppliers (of civilian aircraft) include the South African Police Services, National Port Authority and Titan Helicopter Group.

Civil rotor wing aircraft not equipped with floatation gear are prohibited from operating far from the coast^[114]. Such operations are restricted to the Territorial Waters, and often even closer, within the Littoral Zone. Rotor wing aircraft equipped with floatation gear are restricted in range from the coast primarily due to fuel limits. For the purposes of this study, the effect due to LACK of floatation gear was ignored. In other words, it has been assumed that any aircraft not equipped with floatation gear as standard could be modified accordingly, thereby allowing maximum range from shore limited only by the fuel supply.

Appendix G contains a detailed summary of the available airborne assets.

7.1.1 South African Air Force (SAAF)

The South African Air Force is the primary supplier of aircraft for domestic Search and Rescue. The SAAF have at their disposal 83 rotary wing and 35 fixed wing aircraft, deployable for maritime Search and Rescue operations. As explained in detail in Appendix G, these aircraft include both deployable (dedicated, equipped types with fully trained crews) and potentially deployable (remote chance) types.

7.1.2. South African Navy (SAN)

Although the South African Navy does not own any aircraft, it does have at its disposal 4 rotary wing aircraft, deployable for maritime Search and Rescue operations.

7.1.3. South African Police Services (SAPS)

According to SASAR, the South African Police Services are not primary suppliers of aircraft for maritime Search and Rescue. Due to the lack of floatation gear, all potential rescue work is carried out very close to the shoreline (maximum 2nmi from the coast). Appendix G contains a summary of the types potentially deployable, in the remote event of this being a requirement. As mentioned, the lack of floatation gear has been ignored in the range analysis.

7.1.4. The National Ports Authority (NPA)

Acher Aviation operates a fleet of 3 helicopters on behalf of the National Ports Authority. The helicopters are primarily used for Marine Pilot Services, but are also employed for maritime SAR, within a 100nm radius from either Durban or Richards Bay, when required^{[31][221]}. Appendix G contains a detailed list of the types available.

7.1.5. Titan Helicopter Group

Titan Helicopter Group have at their disposal 12 rotary wing and 2 fixed wing assets, deployable for maritime Search and Rescue operations. Appendix G contains a detailed list of the types available.

7.2. Domestic Search and Rescue Aircraft: Key Performance Figures

Table 7.1 summarises the key performance figures (maximum cruise speed and maximum range and endurance at maximum at cruise speed) for each aircraft type. Refer to Appendix H for a detailed analysis of how these figures were derived.

Aircraft Type	S_{Max} (nmi)	V_{Cruise} (kn)	T_{Max} (h)
Agusta Westland A109 LUH	500	153	3h16m
Agusta Westland A109E Power	512	154	3h19m
Agusta Westland A109S Grand	424	156	2h43m
Beech King Air 200/B200C	1974.3	289.4	6h49m
Beech King Air 300	1960.4	315.4	6h12m
Bell 212 Twin Huey	236.4	100	2h21m
CASA 212-200/300	800	180	4h26m
CASA CN-235 (prototype)	2000	230	8h42m
Cessna C208A Caravan	869	175	5h
Convair 580	1200	280	4h17m
Denel Oryx M1/M2	827	120	6h53m
Douglas C47-TP MP&NT	1300	160	8h7m
Eurocopter AS 350 B3	359	140	2h33m
Eurocopter EC 120B Colibri	383	120	3h11m
Kamov Ka-32A	475	118.8	4h
Lockheed C-130BZ Hercules	2699.8	300	9h
MBB BO105 CBS-5	600	134	4h28m
MBB/Kawasaki BK117	307.6	133.8	2h17m
MD Helicopters MD-500E	287	170	1h41m
Mil Mi-8 MTV	567	116	4h53m
Mil Mi-8 P	737	116	6h21m
Pilatus PC-6 Porter	500	125	4h
Pilatus PC-12	1560	280	5h34m
Robinson R44 Raven II	304.1	117	2h35m
Sikorsky S-61N MkII	400.6	114.4	3h30m
Sikorsky S-76A++ Spirit	411	137	3h
Westland Super Lynx 300	280	132	2h7m

Table 7.1: Domestic Maritime Search and Rescue Aircraft: Key Performance Figures

7.3. Domestic Search and Rescue Aircraft: Special SAR Equipment

Table 7.2 summarises the special SAR equipment configurations as standard fitment on the aircraft types as operated locally and as identified in Table 7.1. Only Special SAR equipment types as specified in Chapter 6 par 6.2 has been considered.

Aircraft Type	Domestic	E_{Search}	E_{Rescue}
Agusta Westland A109 LUH		FLIR SAR DF	none
Agusta Westland A109E Power		Radar (weather only)	none
Agusta Westland A109S Grand		Radar (weather only)	SATCOM
Beech King Air 200/B200C		Radar (weather only)	
Beech King Air 300		Radar (weather only)	
Bell 212 Twin Huey		Radar (weather only)	none
CASA 212-200/300		Radar (weather only)	none
CASA CN-235 (prototype)		Radar (weather only)	
Cessna C208A Caravan		Radar (weather only)	none
Convair 580		Radar (weather only)	None
Denel Oryx M1/M2		Radar (weather only) SAR DF	
Douglas C47-TP MP&NT		Radar (weather only)	MLM ALSC
Eurocopter AS 350 B3		FLIR (SAPS)	none
Eurocopter EC 120B Colibri		none	none
Kamov Ka-32A		MSR	none
Lockheed C-130BZ Hercules		Radar (weather only)	MLM ALSC
MBB BO105 CBS-5		FLIR (SAPS)	none
MBB/Kawasaki BK117		FLIR (SAPS)	none
MD Helicopters MD-500E LEH		FLIR	none
Mil Mi-8 MTV		Radar (weather only)	none
Mil Mi-8 P		none	none
Pilatus PC-6 Porter		FLIR	none
Pilatus PC-12		Radar (weather only)	
Robinson R44 Raven II		FLIR	none
Sikorsky S-61N MkII		Radar (weather only)	none
Sikorsky S-76A++ Spirit		Radar (weather only)	SATCOM
Westland Super Lynx 300		FLIR MSR SAR DF	SATCOM

Table 7.2: Domestic Maritime Search and Rescue Aircraft: Special SAR Equipment Configurations

7.4. Conclusion

South Africa is in possession of a number of capable aircraft types deployable for maritime Search and Rescue operations. The full extent of the capability will be measured in Chapter 10, by comparing these key performance figures and special SAR equipment configurations with the requirements derived in Chapters 5 and 6.

Chapter 8

8. Maritime Search and Rescue Aircraft: Foreign

This chapter examines which aircraft types are currently available on the International front, and are deployable for maritime Search and Rescue missions. As for the domestic analysis in the previous chapter, special attention will be given to their key performance figures, as well as special SAR equipment configurations.

8.1. Foreign Search and Rescue Aircraft: Key Performance Figures

Table 8.1 summarises the key performance figures (maximum cruise speed and maximum range and endurance at maximum at cruise speed) for each aircraft type. To avoid duplication, domestic types already covered in Chapter 7, but which are also used by foreign operators, have not been repeated in this table. Additionally, unmanned systems are covered in a separate chapter. Refer to Appendix H for a detailed analysis of how these figures were derived.

It should furthermore be note that the following aircraft are either proposed development models or are still in development and therefore performance figures are best estimates supplied by the respective Design Organisations:

- Alenia/ATR 72 ASW
- Dassault Falcon 900 MPA

Aircraft Type	S_{Max} (nmi)	V_{Cruise} (kn)	T_{Max} (h)
Agusta Westland AW139	573	165	3h28m
Agusta Westland Merlin HM1	900	136	6h37m
Alenia/ATR 42 MP Surveyor	2020	190	10h37m
Alenia/ATR 72 ASW	1505	145	10h22m
Alenia C27J Spartan	3200	325	9h50m
BAe Nimrod MRA4	6000	442.8	13h33m
Bell 214 ST	435.4	140	3h6m
Bell 407	383	118	3h14m
Bell 412 EP	423	131	3h13m
Bell 427	400	133	3h
Bell 429	350	142	2h27m
Bell/Agusta BA 609	700	275	2h32m
Bell/Boeing MV-22B Osprey	1800	250	7h12m
Bell UH-1Y Venom	260	135	1h55m
Boeing P-8A Poseidon	3160	490	6h26m
Bombardier/DHC Dash 8 Q200	973	290	3h21m
Bombardier/DHC Dash 8 Q400	1526	361	4h13m
CASA CN-235MP Persuader	2300	130	17h41m
CASA C-295 Persuader	2400	145	16h33m
Dassault Atlantique ATL2	4900.2	299.8	16h20m
Dassault Falcon 900 MPA	4100	496.1	8h15m
Embraer P-99 (EMB 145 MP)	2050	444.1	4h36m
Eurocopter AS 332 L2 Super Puma	446	150	3h
Eurocopter AS 365 N3 Dauphin	427	145	3h
Eurocopter AS 532 SC Cougar	492	136	3h37m
Eurocopter AS 555 Fennec	375	118	3h10m
Eurocopter AS 565 Panther	427	145	3h
Eurocopter EC 225 Super Puma	506	141.5	3h34m
Eurocopter EC 725 Cougar	692	141	4h54m
Eurocopter MH-65C Dolphin	300	165	1h49m
Fairchild-Dornier Do-228-101 MPA	1722.3	165.1	10h25m
Fokker 50 Maritime	2340	150	15h36m
Ilyushin Il-38 May	4049.4	348.5	11h37m
Kaman SH-2G Super Seasprite	540	120	4h30m
Lockheed HC-130J Hercules	5500	339	16h13m
Lockheed P-3C Orion	4760	328	14h30m
Lockheed CP-140 Aurora			
MD Helicopters MD-600N	423	115	3h40m
NH Industries NH90 FSH/NFH	659	132	5h
Reims-Cessna F406	1200	246	4h52m
Shaanxi Y-8X MPA	4211	350	12h1m
Sikorsky CH-148 Cyclone (MH-92)	525	137	3h49m
Sikorsky CH-53E Super Stallion	1119.9	150.1	7h27m
Sikorsky MH-53E Sea Dragon	1050	150	7h
Sikorsky MH-60J Jayhawk	300	170	1h45m
Sikorsky S-70B Sea Hawk	450	146	3h4m
Tupolev Tu-142M Bear-F	6775	500	13h33m

Table 8.1: Foreign Maritime Search and Rescue Aircraft: Key Performance Figures

8.2. Foreign Search and Rescue Aircraft: Special SAR Equipment

Table 8.2 summarises the special SAR equipment configurations as standard fitment on the aircraft types identified in Table 8.1, and as configured for Maritime SAR. The best-case scenario was chosen for each aircraft type; it is very difficult to provide a generic configuration, since it is largely customer driven. Only Special SAR equipment types as specified in Chapter 6 par 6.2 has been considered. Options in italics indicate equipment features presumed standard, but for which no substantiation could be found.

Aircraft Type ^{Foreign}	E_{Search}	E_{Rescue}
Agusta Westland AW139	FLIR MSR	
Agusta Westland Merlin HM1	FLIR MSR SAR DF	SATCOM
Alenia/ATR 42 MP Surveyor	FLIR MSR SAR DF	MLM (by hand) ALSC
Alenia/ATR 72 ASW	FLIR MSR SAR DF	MLM (by hand) ALSC
Alenia C27J Spartan	Radar (weather and tactical) SAR DF	SATCOM
BAe Nimrod MRA4	FLIR MSR SAR DF	SATCOM
Bell 214 ST	Radar (weather only)	none
Bell 407	FLIR	none
Bell 412 EP	FLIR Radar (weather only)	none
Bell 427	<i>Radar (weather only)</i>	none
Bell 429	FLIR	None
Bell/Agusta BA 609	<i>Radar (weather only)</i>	none
Bell/Boeing MV-22B Osprey	FLIR Radar (weather and tactical) SAR DF	SATCOM
Bell UH-1Y Venom	FLIR	SATCOM
Boeing P-8A Poseidon	FLIR MSR SAR DF	SATCOM
Bombardier/DHC Dash 8 Q200	FLIR (MSA version) ESM (MSA version) SAR DF (MSA version)	SATCOM (MSA version) MLM (MSA version, by hand) ALSC (MSA version, by hand)
Bombardier/DHC Dash 8 Q400	Radar (weather only)	none
CASA CN-235MP Persuader	FLIR MSR SAR DF	SATCOM MLM (by hand) ALSC (by hand)
CASA C-295 Persuader	FLIR MSR SAR DF	SATCOM MLM (by hand) ALSC (by hand)
Dassault Atlantique ATL2	FLIR MSR	SATCOM MLM

	<i>SAR DF</i>	<i>ALSC</i>
Dassault Falcon 900 MPA	FLIR MSR <i>SAR DF</i>	SATCOM MLM ALSC
Embraer P-99 (EMB 145 MP)	FLIR MSR <i>SAR DF</i>	SATCOM MLM ALSC (by hand)
Eurocopter AS 332 L2 Super Puma	Radar (weather only)	none
Eurocopter AS 365 N3 Dauphin	Radar (weather only) FLIR	none
Eurocopter AS 532 SC Cougar	FLIR MSR <i>SAR DF</i>	none
Eurocopter AS 555 Fennec	FLIR MSR <i>SAR DF</i>	none
Eurocopter AS 565 Panther	FLIR MSR <i>SAR DF</i>	none
Eurocopter EC 225 Super Puma	FLIR MSR <i>SAR DF</i>	none
Eurocopter EC 725 Cougar	FLIR MSR <i>SAR DF</i>	none
Eurocopter MH-65C Dolphin	Radar (weather only) FLIR	MLM
Fairchild-Dornier Do-228-101 MPA	FLIR MSR <i>SAR DF</i>	<i>MLM (by hand)</i> ALSC (by hand)
Fokker 50 Maritime	FLIR MSR <i>SAR DF</i>	SATCOM MLM ALSC (by hand)
Ilyushin Il-38 May	FLIR MSR	<i>SATCOM</i>
Kaman SH-2G Super Seasprite	FLIR MSR <i>SAR DF</i>	none
Lockheed HC-130J Hercules	FLIR MSR <i>SAR DF</i>	SATCOM <i>MLM (by hand)</i> ALSC (by hand)
Lockheed P-3C Orion Lockheed CP-140 Aurora	FLIR MSR <i>SAR DF</i>	SATCOM MLM
MD Helicopters MD-600N	FLIR	
NH Industries NH90 FSH/NFH	FLIR MSR <i>SAR DF</i>	SATCOM ALSC
Reims-Cessna F406	FLIR MSR	
Shaanxi Y-8X MPA	FLIR MSR <i>SAR DF</i>	ALSC

Sikorsky CH-148 Cyclone (MH-92)	FLIR MSR SAR DF	SATCOM
Sikorsky CH-53E Super Stallion	FLIR Radar (weather and tactical)	none
Sikorsky MH-53E Sea Dragon	Radar (weather and tactical)	none
Sikorsky MH-60T Jayhawk	FLIR MSR SAR DF	ALSC
Sikorsky S-70B Sea Hawk	FLIR MSR <i>SAR DF</i>	ALSC
Tupolev Tu-142M Bear-F	FLIR MSR	SATCOM

Table 8.2: Foreign Maritime Search and Rescue Aircraft: Special SAR Equipment Configurations

8.3. Conclusion

Foreign operators are in possession of a number of capable aircraft types deployable for maritime Search and Rescue operations. The full extent of the capability will be measured in Chapter 10, by comparing these key performance figures and special SAR equipment configurations with the requirements derived in Chapters 5 and 6.

Chapter 9

9. Maritime Search and Rescue Aircraft: Unmanned

Many countries employ unmanned aircraft for various tasks. This chapter examines which unmanned aircraft types are currently available and deployable for maritime^{[243][244]} Search and Rescue tasks. As for the domestic and foreign analysis in the previous chapters, special attention will be given to their key performance figures, as well as special SAR equipment configurations.

9.1. Unmanned Search and Rescue Aircraft: Key Performance Figures

Table 9.1 summarises the key performance figures (maximum cruise speed and maximum range and endurance at maximum at cruise speed) for each aircraft type. In addition to these three figures, the maximum communications range for each unmanned aircraft system has been included. Many unmanned aircraft are limited in range simply due to limits in communications range. Unmanned aircraft typically employ either a line-of-sight link, or a beyond-visual-range satellite link^{[236][245]}, or a combination. Line-of-sight links limit the operational radius (and therefore the maximum search range) to around 110nmi (~200km)^[236] from the base of operations. Many of these aircraft can, however, remain in the air at this limited range for many hours, thereby increasing Search Time and endurance.

Refer to Appendix H for a detailed analysis of how these figures were derived.

It should furthermore be note that the following aircraft are either proposed development models or are still in development and therefore performance figures are best estimates supplied by the respective Design Organisations:

- Denel Dynamics Bateleur

Aircraft Type ^{Unmanned}	S_{Comms} (nmi)	S_{Max} (nmi)	V_{Cruise} (kn)	T_{Max} (h)
AAI RQ-7B Shadow 200	68	540	90	6h
BAe HERTI	Range max	2250	90	25h
Bell TR916 Eagle Eye	100	800	200	4h
Boeing A160T Hummingbird	110	2250	112.5	20h
Denel Dynamics Bateleur	Satcom	2430	135	18h
EADS ORKA-1200	Tactical 110	842	105.3	8h
Elbit Hermes 450	108 (std)	1400	70	20h
Elbit Hermes 1500	108 (std)	2080	80	26h
General Atomics RQ-1/MQ-1 Predator	Satcom	4800	120	40h
General Atomics MQ-9 Reaper	Satcom	7200	240	30h
General Atomics Mariner	Satcom	7100	157	45h13m
IAI Heron TP (Eitan)	Satcom	7200	200	36h
IAI/EADS Eagle 1/Heron 1/Harfang	Satcom	2400	80	30h
IAI/EADS Eagle 2	Satcom	4320	180	24h
IAI/PUI RQ-2 Pioneer	100	495	110	4h30m
InSitu/Boeing ScanEagle	Range max	980	49	20h
Northrop Grumman MQ-8B Fire Scout	110	880	110	8h
Northrop Grumman RQ-4A Global Hawk	Satcom	12000	343	35h
RUAG Ranger	97	630	70	9h
SAAB Skeldar V-200	81	350	70	5h
Sagem Sperwer B	108	972	81	12h
Schiebel Camcopter	97	330	55	6
Swift Killer Bee	50	972	64.8	15
Warrior/Aero-Marine Gull 68	100	1124	100	11h14m

Table 9.1: Unmanned Maritime Search and Rescue Aircraft: Key Performance Figures

9.2. Unmanned Search and Rescue Aircraft: Special SAR Equipment

Table 9.2 summarises the special SAR equipment configurations as standard fitment on the aircraft types identified in Table 9.1, and as configured for Maritime SAR. The best-case scenario was chosen for each aircraft type; it is very difficult to provide a generic configuration, since it is largely customer driven. Only Special SAR equipment types as specified in Chapter 6 par 6.2 has been considered. Options in *italics* indicate equipment features presumed standard, but for which no substantiation could be found.

Aircraft Type ^{Unmanned}	E_{Search}	E_{Rescue}
AAI RQ-7B Shadow 200	FLIR	
BAe HERTI	FLIR	
Bell TR916 Eagle Eye	FLIR MSR	
Boeing A160T Hummingbird	FLIR or Radar (tactical)	
Denel Dynamics Bateleur	FLIR MSR	SATCOM
EADS ORKA-1200	FLIR MSR	
Elbit Hermes 450	FLIR or Radar (tactical)	SATCOM
Elbit Hermes 1500	FLIR MSR	SATCOM
General Atomics RQ-1/MQ-1 Predator	FLIR MSR	SATCOM
General Atomics MQ-9 Reaper	FLIR MSR	SATCOM
General Atomics Mariner	FLIR MSR	SATCOM
IAI Heron TP (Eitan)	FLIR MSR	SATCOM
IAI/EADS Eagle 1/Heron 1/Harfang	FLIR MSR	SATCOM
IAI/EADS Eagle 2	FLIR MSR	SATCOM
IAI/PUI RQ-2 Pioneer	FLIR	
InSitu/Boeing ScanEagle	FLIR	
Northrop Grumman MQ-8B Fire Scout	FLIR or Radar (tactical)	
Northrop Grumman RQ-4A Global Hawk	FLIR MSR	SATCOM
RUAG Ranger	FLIR or Radar (tactical)	
SAAB Skeldar V-200	FLIR or Radar (tactical)	
Sagem Sperwer B	FLIR Radar (tactical)	
Schiebel Camcopter	FLIR or Radar (tactical)	
Swift Killer Bee	FLIR	
Warrior/Aero-Marine Gull 68	FLIR MSR	MLM, ALSC

Table 9.2: Unmanned Maritime Search and Rescue Aircraft: Special SAR Equipment Configurations

9.3. Conclusion

Foreign and domestic operators are in possession of a number of capable unmanned aircraft types deployable for maritime Search and Rescue

operations. The full extent of the capability will be measured in Chapter 10, by comparing these key performance figures and special SAR equipment configurations with the requirements derived in Chapters 5 and 6.

Chapter 10

10. Existing Search and Rescue Aircraft: Shortcomings

The quantified key performance requirements and defined special SAR equipment will now be mapped against those of the existing maritime Search and Rescue aircraft, as identified and listed in Chapters 7, 8 and 9. Shortcomings will be shown for each aircraft type, per search location.

The detailed analysis is contained in Appendix J.

10.1. Existing Search and Rescue Aircraft Shortcomings: Performance

From this analysis, a summary of shortcomings can be presented concerning the performance of all existing aircraft types currently deployable for maritime Search and Rescue tasks. Shortcomings are shown per search location.

10.1.1. Territorial Waters

Of those analysed, 29.6% of Domestic, 41.3% of Foreign and 37.5% of Unmanned types exhibit inherent performance characteristics to enable them to perform effective Search and Rescue within the Territorial Waters.

To conclude, there are sufficient aircraft types available to perform effective maritime Search and Rescue within the boundaries of the Territorial Waters.

10.1.2. Contiguous and Maritime Cultural Zone

Of those analysed, 25.9% of Domestic, 41.3% of Foreign and 37.5% of Unmanned types exhibit inherent performance characteristics to enable them to perform effective Search and Rescue within the Contiguous and maritime Cultural Zone.

To conclude, there are sufficient aircraft types available to perform effective maritime Search and Rescue within the boundaries of the Contiguous and Maritime Cultural Zone.

10.1.3. Exclusive Economic Zone

Of those analysed, 0% of Domestic, 17.4% of Foreign and 37.5% of Unmanned types exhibit inherent performance characteristics to enable them to perform effective Search and Rescue within the Exclusive Economic Zone.

To conclude, there are sufficient Unmanned aircraft types available to perform effective maritime Search and Rescue within the boundaries of the Exclusive Economic Zone. There are only marginally sufficient Foreign types available for this task, and none of the Domestic aircraft types analysed are capable of performing effective maritime Search and Rescue beyond the boundaries of the C&MCZ.

10.1.4. Continental Shelf

Of those analysed, 0% of Domestic, 2.2% of Foreign and 37.5% of Unmanned types exhibit inherent performance characteristics to enable them to perform effective Search and Rescue within the Continental Shelf zone.

To conclude, there are sufficient Unmanned aircraft types available to perform effective maritime Search and Rescue within the boundaries of the Continental Shelf zone. Only one Foreign type analysed is capable of performing this task efficiently, and none of the Domestic aircraft types analysed are capable of performing effective maritime Search and Rescue beyond the boundaries of the C&MCZ.

10.1.5. Marion Island Rim

Of those analysed, 0% of Domestic, 0% of Foreign and 3.7% of Unmanned types exhibit inherent performance characteristics to enable them to perform effective Search and Rescue within the Continental Shelf zone

To conclude, only one of the Unmanned aircraft types analysed is capable of performing this task efficiently. None of the Foreign aircraft types analysed are capable of performing effective maritime Search and Rescue beyond the boundaries of the CS. None of the Domestic aircraft types analysed are capable of performing effective maritime Search and Rescue beyond the boundaries of the C&MCZ.

10.1.6. Search Extremities

In consideration of key performance, none of the 97 aircraft types analysed are capable of performing effective maritime Search and Rescue to the extremities of the national Search and Rescue Region.

10.2. Existing Search and Rescue Aircraft Shortcomings: Special SAR Equipment

From this analysis, a summary of shortcomings can be presented concerning the special SAR equipment configurations of all existing aircraft types currently deployable for maritime Search and Rescue tasks.

10.2.1. Special SAR Equipment

In consideration of special equipment, none of the 27 Domestic aircraft types analysed are equipped (as standard) with the full compliment of the special SAR equipment types required for effective maritime Search and Rescue.

In consideration of special equipment, none of the 24 Unmanned aircraft types analysed are equipped (as standard) with the full compliment of the special SAR equipment types required for effective maritime Search and Rescue.

Of the 46 Foreign aircraft types analysed, eight types are potentially fully equipped. This remains inconclusive and an estimation only (refer par 8.2 for clarification).

10.3 The Need

The greatest need, in terms of the national maritime Search and Rescue asset capability, is therefore to find an asset capable of meeting the key performance requirements for the region beyond the Marion Island Rim and up to the Search Extremities, whilst meeting the full special SAR equipment configuration requirement.

10.4. Conclusion

In conclusion, the analysis contained in Part 1 has provided an overview of the conditions, including natural, environmental, political, legal, organisational and physical, which have an impact on maritime Search and Rescue in South

Africa. The analysis has determined the performance and equipment requirements for airborne maritime Search and Rescue assets, and the specific environment in which these aircraft will be required to function.

The analysis has taken a specific in-depth look into the performance figures and equipment levels for existing aircraft currently deployable for Search and Rescue, and has considered domestic, foreign and unmanned types. A comparison was made, and consideration was given to six locations across the national maritime Search and Rescue Region. Finally, shortcomings were identified, and the greatest need concerning airborne assets for maritime Search and Rescue in South Africa has been deduced.

In consideration of the above and the deductions made, it has been determined that the greatest immediate need is for an asset capable of providing effective and efficient Search and Rescue services beyond the 1770nmi Marion Island Rim and up to the Search Extremities, whilst meeting the full special SAR equipment configuration requirement.

Part 2 of this thesis focuses on presenting a concept specification for an aircraft system capable of fulfilling this need.

PART 2

Unmanned Aircraft System Specification and Concept

Chapter 11

11. Introduction to Unmanned Aerial Vehicles

11.1. Definition of an Unmanned Aerial Vehicle

There are various definitions for an Unmanned Aerial Vehicle (UAV)^[96]. The list below summarises a few of the most acceptable variations:

- “A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles. Also called UAV.”^[1]
- “An unmanned aerial vehicle is a remotely controlled or autonomous aircraft used for surveillance and strike missions. Known as UAV's, these aircraft are useful in situations where it is too dangerous to use manned aircraft.”^[2]
- “The UAV is an aircraft designed from the outset to be flown without an onboard pilot. The UAV is aerodynamically supported.”^[3]
- “A UAV is an aircraft which is designed to operate with no human pilot on board, and more generally here with no human being on board.”^[4]
- “A device used or intended to be used for flight in the air that has no onboard pilot. This includes all classes of airplanes, helicopters, airships, and translational lift aircraft that have no onboard pilot. Unmanned aircraft are understood to exclude traditional balloons.”^[5]
- “A device that is used or intended to be used for flight in the air that has no onboard pilot. This includes all classes of airplanes, helicopters, airships, and translational lift aircraft that have no onboard pilot.”^[6]
- “An aircraft which is designed to operate with no human pilot on board and which does not carry personnel. Moreover a UAV is capable of

sustained flight by aerodynamic means; is remotely piloted or automatically flies a pre-programmed flight profile; is reusable; is not classified as a guided weapon or similar one shot device designed for the delivery of munitions.”^[7]

From the above definitions, it is clear that a UAV exhibits the following basic characteristics:

- It is remotely piloted, operated and controlled;
- It contains no crew on-board;
- It is reusable (excludes missiles and ballistics);
- It excludes traditional balloons;
- It includes unmanned aircraft, helicopters, airships and translational lift aircraft;
- It is capable of sustained, controlled flight;
- It is aerodynamically supported;
- UAVs may be used where it is too dangerous to use manned aircraft;

Similarly, various definitions exist for an Unmanned Aerial System (UAS)^{[74][105]}. The following provide examples:

- “The UAV System comprises all those surface borne and airborne elements necessary to achieve the specified operational objectives. The system shall ensure that the UAV is always under control. It will be commanded by internal system and/or external communications links.”^[3]
- “A UAV System comprises individual UAV System elements consisting of the air vehicle (UAV), the remote control station and any other UAV System elements necessary to enable flight such as a command and control data link, communication system and launch and recovery

elements. There may be multiple UAV, remote control stations, or launch and recovery elements within a UAV System^[8].”

- “The combination of unmanned aircraft (UA), system elements necessary to enable the taxiing, takeoff/launch, flight and recovery/landing of UA, and the elements required to accomplish its mission objectives. The system elements include control stations, software, health monitoring, communication, control and data links, data terminals, payloads, launch & recovery elements, flight termination systems, support & maintenance equipment, power generation, distribution & supply, ATC communications equipment, handling, storage & transport equipment, and related documentation^[9].”
- “A UAV System comprises individual UAV System elements consisting of the aerial vehicle (UAV), the UAV control station and any other UAV System elements necessary to enable flight such as a command and control data link, communication system and take-off and landing element. There may be multiple UAV, UCS, or takeoff and landing elements within a UAV System^[7].”

From the above definitions, it is clear that a UAV System includes at least the following basic elements^[105]:

- The air vehicle (aircraft);
- Payloads;
- Communications Links (command & control, voice, data, ATC);
- Air vehicle Command & Control (flight control) station(s);
- Payload control and payload data reception, recording, manipulation, analysis and distribution workstation(s);
- Taxi elements;
- Launch elements;

- Recovery elements;
- System health monitoring;
- Flight termination elements;
- Scheduled and unscheduled maintenance elements;
- Aircraft, payload and equipment handling elements;
- Transportation elements;
- Storage elements;
- Ground power generation, distribution and supply elements;
- Training elements;
- Logistic supply and support elements;
- Documentation

As of 2009, ICAO has indicated that the various terms used for UAVs (Unmanned Aerial Vehicle, Remotely Piloted Vehicle, Remotely Piloted Aircraft, etc) will be replaced by the single generic term “Unmanned Aircraft” (UA)^[74]. Similarly, the System will be known as an “Unmanned Aircraft System” (UAS)^[74]. This terminology has henceforth been adopted throughout this thesis.

11.2. History of Unmanned Aircraft^[106]

Unmanned Aircraft have been in use since 1849^[10]. World Wars I and II saw varied experimentation with unmanned versions of manned aircraft^{[11][12][13][15]} as well as guided weapons^{[16][17]}. It was during the 1980's, however, that true unmanned aircraft were first put to use in large numbers. The first effective use of modern UAs was undertaken by the Israelis in the early 1980's during the Syrian War^[21].

Since then, Unmanned Aircraft have proliferated and are being utilised by both military and civil operators for numerous functions and missions. The following sub-section will touch on the varied uses for Unmanned Aircraft Systems.

11.3. Typical Uses for Unmanned Aircraft

Unmanned Aircraft are versatile, with many uses, both military and civil. As shown in the previous section, the first uses were of a military nature, and included aerial bombs and torpedoes, target drones, decoys and reconnaissance work.

Modern uses include, but are by no means limited to, the following^{[29][81][84][93][95][96][101][104][105][107]}.

- Surveillance;
- Reconnaissance;
- Intelligence gathering;
- Airborne targets;
- Battlefield targeting;
- Battlefield damage assessment;
- Military strike and attack;
- Meteorological and environmental information;
- Search and Rescue;
- Provision of situational awareness;
- Communications relay;
- Command and Control.

11.4. UA Categorisation (Types of UAs)

There is no single standard for categorisation of UAs. Various methods are used, of which the following prove to be useful:

- The United States military “TIER” system;
- Function, purpose, mission, task or role;
- Performance.

All three these methods do exhibit some commonality or “overlap”, and a single UA could be categorised by combining all three methods, if required.

11.4.1 TIER System

The United States Air Force (USAF), United States Marine Corps (USMC) and United States Army (US Army) have developed and adopted the “TIER” system to categorise their UAs^[29]. The TIER system is not standardised among the three Arms of Force, each one differing to a degree from the other^[29]. The TIERs are as follows^[29]:

- TIER N/A
- TIER I
- TIER II
- TIER II+
- TIER III-
- TIER III

Appendix O provides additional details of how the various TIERs related to the various Arms of Force, with examples.

11.4.2. Function, Purpose, Mission, Task or Role

UAs can also be categorised by function, purpose, mission, task or role (in short, its intended use)^[29].

- Target
- Decoy
- Reconnaissance and/or Surveillance
- Combat
- Logistic Supply
- Research and Development
- Civil and Commercial

Appendix O provides additional details of each usage type, with examples.

11.4.3. Performance

UAs can also be categorised by altitude, range and/or endurance, and/or other basic performance parameters^{[29][83]}:

- Handheld
- Close
- NATO
- Tactical
- Medium Altitude, Long Endurance (MALE)
- High Altitude, Long Endurance (HALE)
- High Speed
- Orbital
- CIS Lunar

Appendix O provides additional details of each performance category, with examples.

The performance figures per category are not rigid, but serve as a guide. Some UAs falling within a specific performance category may have other performance figures that fall outside the limits, but remain eligible for that category. An example is the Denel Dynamics Seeker II, which falls within the “Tactical” category, but which has a range figure in excess of the specified “limit”.

A single UA can be categorised either according to one, or a combination of, categorisation methods. As an example, the Northrop Grumman RQ-4 Global Hawk can be categorised as a TIER II+ Reconnaissance/Surveillance AND/OR Civil/Commercial HALE UA, or any combination thereof, depending on the circumstances.

11.5. Conclusion

This Chapter has evaluated and provided a definition for an Unmanned Aircraft (UA) and Unmanned Aircraft System (UAS). Furthermore, it has been determined that UAs have been in development and in use since before World War I and are utilised for many tasks, amongst others Search and Rescue. Following the study into the categorisation of UAs, it can be predicted that the UA/UAS being envisaged for this concept can be categorised as a Civil High Speed HALE SAR UAS.

Chapter 12

12. Advantages and Disadvantages of Unmanned Aircraft

This section discusses the advantages and disadvantages of unmanned aircraft when compared manned aircraft, in context of similar utilisation.

12.1. Advantages of Unmanned Aircraft

UAs have certain inherent advantages over manned aircraft. The following section will define and discuss these advantages.

12.1.1. The Three D's: Dull, Dangerous and Dirty

Arguably the top three advantages UAs exhibit over manned aircraft are summarised by the “Three D’s” – dull, dangerous and dirty^{[95][96][101][105][107]}. UAs are ideally suited to operate in missions or carry out tasks involving any one, or combinations, of these three aspects.

12.1.1.1. Dull Missions

Dull missions usually involve lengthy transit times, and/or some element of persistence or endurance^[58]. The “dull” portions are those parts of the mission requiring little or no direct interaction between the pilot and the aircraft. Typical dull missions, or missions segments, include:

- Ferry flights
- Long cargo haul flights
- International commercial airline flights
- The search and transit portions of Search and Rescue
- Intelligence, surveillance, reconnaissance (ISR)
- Airborne communications relay
- Airborne early warning and control (AEW&C)
- In-flight refuelling (loiter phase)

Dull missions can lead to fatigue and a lapse in concentration by the pilot, which in turn has a direct impact on the safety of rest of the crew and passengers, and the overall success of the mission itself. To counter this, manned aircraft and missions falling into this category require crew duty cycles and rest facilities to afford critical crew members the opportunity to recover strength, as well as multiple swap-out critical crew members on-board. Many aircraft do operate on auto-pilot during tedious stretches of a mission, but still require the pilot to take over at short notice. UAs have the advantage of being able to operate autonomously^{[74][95][97]}, while affording pilots to exchange with fresh crews in the middle of an operation and at regular intervals without interfering with or negatively affecting the mission.

12.1.1.2. Dangerous Missions

Dangerous military and paramilitary missions are those involving possible engagement with enemy forces. It may involve engagement with enemy forces on own territory, or require entry into enemy territory for the purposes of reconnaissance, surveillance, peace enforcement, or weapons delivery^{[79][82]}.

Dangerous non-military (civil) missions include flight into geographically challenging and potentially hazardous terrain, or into extreme weather^{[78][79][82]}. Examples include flight in or around volcanoes, the Polar Regions, mountainous areas, extreme altitudes, extreme wind conditions, flight over the Open Ocean, flights into hurricanes, cyclones and blizzards, flight into known icing conditions, as well as sustained flight into conditions of poor visibility, e.g. sleet, fog, heavy rain, smoke or haze^[101].

UAs are essentially expendable and do not expose airborne crews to these dangers^{[58][59][60]}. They can also be designed with less “damage tolerance” or survivability features (depending on the precise nature of its use) due to the absence of humans on-board.

12.1.1.3. Dirty Missions

These involve entry into contaminated places^[58], typically radiated and biologically or chemically polluted areas. As with Dangerous missions, use of

an unmanned aircraft in these conditions will safeguard conventional crews and ground personnel from exposure and contamination^{[59][60]}.

12.1.2. System Complexity

UAs tend to be less complex when compared with manned systems^[60], primarily due to the fact that support for human occupancy is completely eliminated from the design. The following systems and sub-systems are omitted when designing UAS air vehicles:

- Cockpit (Ground Control Centre contains the “cockpit”)
- Cabin (Ground Control Centre contains the “cabin”)
- Pressurisation systems
- G-suit system
- Oxygen supply (bottles or OBOGS) and distribution system
- Cockpit and cabin lighting systems
- Crew fresh air supply and ventilation
- Crew water supply
- Galleys
- Ablution facilities
- Crew rest facilities
- Item stowage (baggage, manuals, personal gear)
- Emergency backup systems, including:
 - Emergency oxygen supply
 - Cockpit and cabin fire protection systems
 - Emergency lighting

- Engine fire suppression (unless specified by the user)
- Crew survival system
 - Dinghies
 - Emergency beacons (ELT, EPIRB, PLB)
 - Emergency rations
 - First aid kit
 - Crew escape system

In addition, the following simplified design approaches are also followed:

- Omission of crash-condition design requirements for crew and occupants.
- Structural design is not limited by human flight load limits.

Sensitive electronic systems may require some degree of local cooling or atmospheric conditioning, but this is in addition to crew conditioning, which is eliminated from the unmanned aircraft.

The omission of complex systems will greatly benefit any aircraft. A reduction in complexity usually translates into a reduction in unscheduled maintenance activities and improved maintainability and reliability, leading to overall higher system availability. Alternatively, “unoccupied volume” may be utilised by adding fuel or mission payload, thereby increasing range and endurance, or expanding on capabilities.

Despite the apparent advantage of having a simpler aircraft, Unmanned Aircraft Systems can become quite complex, due to the inherent complexity of data links, remotely located controls, sense-and-avoid technologies and the like. In addition, many of the systems omitted from the air vehicle are required in the Ground Control Station.

12.1.3. Aircraft Size and Weight

Due to the omission of many systems essential for manned aircraft, UAs tend to be smaller and weigh less than their equivalent manned counterparts^{[59][60]}. A reduction in size and weight improves and simplifies transportability, storage requirements and manhandling, while offering easier deployment. It also translates into fuel efficiency, due to reduced powerplant requirements.

For certain roles, the smaller size of a UA may provide an added tactical advantage, in that it is more difficult to detect visually and electronically^{[59][60]}. Reduced weight also potentially translates into shorter runways. Many UAs require no runways, being small or light enough to be launched with catapults and recovered with arrester wires or nets. Vertical take-off types obviously require no runways, but also benefit from a reduction in weight.

12.1.4. Expendability

Unlike manned assets, UAs do not carry human occupants, therefore the loss of such a system, although expensive, is less traumatic due to the omission of the “human factor”^{[58][59][60]}. UAs are essentially expendable, negating the need to deal with the added trauma of human casualties, injuries or prisoners of war.

12.1.5. Development Time and Cost

Development and maintenance costs are potentially less for UAs^{[59][60][76][81][105][107]} due to lower complexity. UAs also tend to be cheaper to procure, as well as to operate and support. Overall Life Cycle Cost is effectively less for unmanned aircraft systems.

Due to lower complexity levels, UAs are often developed far quicker than conventional manned systems^{[75][90]}. Many UAs (even complex machines) have been designed and developed in mere months^{[60][61][62]}. This is strategically advantageous to any potential customer wishing to field a solution in the shortest possible time, while cutting on development cost.

12.1.6. Advantages Compared with Satellites

Surveillance and reconnaissance UAs offer much the same capabilities as many surveillance and reconnaissance satellites, with the added advantage of providing cover at short notice, rather than having to wait for a scheduled pass. Additionally, UAs can scan below cloud cover, fly close to the surface if required and are far cheaper to develop and deploy than satellites^{[59][60]}. UAs also provide information at high-resolution, whereas satellites provide information only at mid-resolution^[72].

12.1.7. Pilot Abilities and Training Cost

Due to the nature of their work, and the risks involved, pilots trained to operate manned systems are highly skilled and expensively trained individuals. Manned pilots require more rigorous training to help endure long or dangerous missions, and have to be fit to endure flight loads. This does not imply complete lack of airmanship – UA pilots still need to know and follow the same rules of the air as for manned systems, and understand the fundamentals of flying. However, UAs are often pre-programmed and operated autonomously, and therefore require less pilot intervention and lower-skilled personnel to interact with or operate them^{[63][73][76][77][86][100]}.

12.2. Disadvantages of Unmanned Aircraft

UAs also exhibit certain inherent disadvantages over manned aircraft. The following section will define and discuss these disadvantages.

12.2.1. Mission Flexibility

Manned aircraft offer greater mission flexibility at present; a human pilot is can think and make intelligent choices intuitively, altering the current mission profile, or switching roles, as required^{[59][60]}. Currently, no form of Artificial Intelligence is powerful or complete enough to offer this level of autonomy to UAs.

Although the ground-based UA pilot can make these decisions, technology currently prevents UAs from operating with full autonomy and “intuitiveness” to the same extent. At present, mission flexibility is offered through human

interaction, where the ground pilot re-programs the flight path, selects new payloads, sends the coordinates and instructions to the UA, and similarly manually re-adjusts the flight path and payloads on completion of the altered mission.

12.2.2. Aircraft Manoeuvrability

Coupled with flexibility is manoeuvrability^{[59][60]}. Manned aircraft, piloted from within, offer their occupants full situational awareness and these pilots have a natural “feel” for manoeuvres and flight loads. Manned aircraft pilots are therefore capable of inducing a greater degree of manoeuvrability into their aircraft, than do unmanned aircraft ground pilots confined to a two-dimensional screen as their only feedback.

12.2.3. Command and Control

Unmanned aircraft have to be controlled and/or piloted remotely, via a command and control (C&C) Data Link. Long range (over-the-horizon, or beyond-line-of-sight) C&C is achievable only via satellite link^{[59][60]} or a relay station. Data links can be sensitive to directionality, sensitivity, signal strength, signal footprint, external electromagnetic interferences and deliberate interference (“hacking”). This requires additional security, design robustness and redundancy, plus additional safety measures, including “auto-return-home” flight modes, in case the link is permanently lost, to save the air vehicle and payloads. Satellite links are also expensive, due to the nature of the infrastructure requirements, and, depending on the service, coverage and bandwidth requirements are potentially limited.

12.2.4. Disadvantages Compared with Satellites

The previous section highlighted the advantages UAs have when compared with satellites. As true as these may be, satellites also have some inherent advantages over UAs. In short:

- Satellites can cover a larger footprint in a shorter time span, and certain satellites can be permanently positioned above a certain point (full-time persistence), whereas even the most persistent UAs cannot^{[59][60]};

- UAs are more vulnerable to ground based air defences than are satellites^{[59][60]}.

12.2.5. Sense and Avoid

The absence of a human pilot onboard the UA removes the added “cover” provided by a pair of human eyes when taking into consideration the avoidance of obstacles. Obstacles include terrain and other air traffic. To try and overcome this problem, UAs are equipped with equipment also essential on manned aircraft. Typical essential equipment includes^{[68][70]}:

- For areas within ground-based radar (ATC) coverage (up to approximately 10 nmi offshore)^[70]:
 - ATC mode C/A/S Transponder [mode S can send data to ATC as well];
 - VHF AM radio (“ATC radio”) in aircraft to relay voice communications between ATC and aircraft;
 - LOS Data Link “voice” carrier to relay ATC communications between aircraft and GCS;
 - LOS Data Link “voice” carrier to relay aircraft communications between aircraft and GCS.
- For ranges beyond ground-based radar (ATC) coverage^[70]:
 - Airborne Collision and Avoidance System (ACAS);
 - Automatic Dependent Surveillance Broadcast (ADS-B)^[95];
 - BLOS (satellite) Data Link “voice” carrier to relay aircraft communications between aircraft, satellite and GCS.
- For all ranges^[70]:
 - V/UHF and HF radios in aircraft to relay voice communications between other aircraft and aircraft
 - Navigation and anti-collision lights
 - Rotating beacon
 - Paint and external markings for high visibility

UA obstacle detection and avoidance technology, commonly referred to as “Sense and Avoid” (or “Detect and Avoid”), has developed somewhat over time, but still has a long way to go, both technologically and legislatively speaking, before becoming commonplace and fully trustworthy^{[74][88][95][102][104][105][108]}. Various User Groups have been created to tackle this daunting task, of which the EUROCAE WG-73 Working Group^{[69][102][104][105][108]} is an example. Sense and Avoid remains a developing field, and the primary means of avoidance is currently still vested in human intervention via the Ground Control Centre.

12.3 Long Range Maritime Search and Rescue: Scoring

The question now remains: in consideration of an airborne system for maritime Search and Rescue, which would be more advantageous to pursue: manned or unmanned. This section analyses the previously discussed advantages and disadvantages, and provides a means of scoring to determine the way forward.

Table 12.1 below provides a summary of all elements discussed in the aforementioned section, and categorises each as either an advantage or disadvantage.

Element	UA: Category
Dull Missions	Advantage
Dangerous Missions	Advantage
Dirty Missions	Advantage
System Complexity	Advantage
Aircraft Size and Weight	Advantage
Expendability	Advantage
Development Time and Cost	Advantage
Satellites	Advantage
Pilot Abilities and Training Cost	Advantage
Mission Flexibility	Disadvantage
Aircraft Manoeuvrability	Disadvantage
Command and Control	Disadvantage
Satellites	Disadvantage
Sense and Avoid	Disadvantage

Table 12.1: Summary of Elements and Categories in terms of UAs

Table 12.2 provides weighting for each element, in terms of its importance to Long Range Maritime Search and Rescue. Weights are from 1 to 5, with 1 being least important, and 5 being essential.

Element	UA: Category	Weights
Dull Missions	Advantage	4
Dangerous Missions	Advantage	4
Dirty Missions	Advantage	1
System Complexity	Advantage	2
Aircraft Size and Weight	Advantage	1
Expendability	Advantage	3
Development Time and Cost	Advantage	3
Satellites	Advantage	4
Pilot Abilities and Training Cost	Advantage	2
Mission Flexibility	Disadvantage	3
Aircraft Manoeuvrability	Disadvantage	1
Command and Control	Disadvantage	5
Satellites	Disadvantage	3
Sense and Avoid	Disadvantage	1

Table 12.2: Weighting, focus on Long Range Maritime Search and Rescue

Table 12.3 expands on each category by sub-categorising each advantage and each disadvantage into Major, Minor and Neutral. The focus is on how advantageous, or disadvantageous, each element will be in consideration of Long Range Maritime Search and Rescue missions.

Element	Category	Sub-category
Dull Missions	Advantage	Major
Dangerous Missions	Advantage	Major
Dirty Missions	Advantage	Neutral
System Complexity	Advantage	Minor
Aircraft Size and Weight	Advantage	Minor
Expendability	Advantage	Major
Development Time and Cost	Advantage	Major
Satellites	Advantage	Major
Pilot Abilities and Training Cost	Advantage	Minor
Mission Flexibility	Disadvantage	Minor
Aircraft Manoeuvrability	Disadvantage	Minor
Command and Control	Disadvantage	Major
Satellites	Disadvantage	Major
Sense and Avoid	Disadvantage	Minor

Table 12.3: Summary of Elements and Sub-categories in terms of UAs, focus on Long Range Maritime Search and Rescue

Table 12.4 provides a score to each sub-category. A major advantage is provided a score of 2, a minor advantage 1, minor disadvantage a –1 and a major disadvantage is scored –2. A neutral impact is scored 0.

Element	Category	Sub-cat	Score
Dull Missions	Advantage	Major	2
Dangerous Missions	Advantage	Major	2
Dirty Missions	Advantage	Neutral	0
System Complexity	Advantage	Minor	1
Aircraft Size and Weight	Advantage	Minor	1
Expendability	Advantage	Major	2
Development Time and Cost	Advantage	Major	2
Satellites	Advantage	Major	2
Pilot Abilities and Training Cost	Advantage	Minor	1
Mission Flexibility	Disadvantage	Minor	-1
Aircraft Manoeuvrability	Disadvantage	Minor	-1
Command and Control	Disadvantage	Major	-2
Satellites	Disadvantage	Major	-2
Sense and Avoid	Disadvantage	Minor	-1

Table 12.4: UA Asset for Maritime SAR: Impact

Table 12.5 sums the scores and weights into a single figure for each element.

Element	Category	Summed Scores
Dull Missions	Advantage	8
Dangerous Missions	Advantage	8
Dirty Missions	Advantage	0
System Complexity	Advantage	2
Aircraft Size and Weight	Advantage	1
Expendability	Advantage	6
Development Time and Cost	Advantage	6
Satellites	Advantage	8
Pilot Abilities and Training Cost	Advantage	2
Mission Flexibility	Disadvantage	-3
Aircraft Manoeuvrability	Disadvantage	-1
Command and Control	Disadvantage	-10
Satellites	Disadvantage	-6
Sense and Avoid	Disadvantage	-1

Table 12.5: Summed Scores

The total score adds up to:

$$8+8+0+2+1+6+6+8+2-3-1-10-6-1 = 41-21 = +20$$

The final scoring indicates that an overall advantage should be achieved in utilising an unmanned aircraft over a manned aircraft for long range maritime Search and Rescue missions^[91]. It would therefore be advantageous to further pursue this avenue in more detail^{[84][93][95][101][107]}.

12.4. Conclusion

This Chapter has shown that UAs exhibit certain inherent advantages over manned aircraft when employed for certain tasks and when operated in certain conditions. The final assessment has shown that this is true for long range maritime Search and Rescue. Although the categories selected, as well as the scoring method, may prove to be subjective, the unmanned system surpasses manned flight for maritime operations by a factor of two. It is therefore concluded that the assessment is sufficiently accurate and that an unmanned aircraft should be ideal for long range maritime Search and Rescue. It would, therefore, be advantageous to further pursue this avenue in more detail.

Chapter 13

13. The Unmanned Aircraft System

The first Section in Part 2 of this thesis provided a definition of an Unmanned Aircraft (UA), as well as the Unmanned Aircraft System (UAS). The aircraft (the UA) is only one aspect of the UAS. Therefore, a concept specification will be provided for the full UAS, capable of satisfying the performance and equipment level requirements analysed in Part 1, for long range maritime Search and Rescue missions.

13.1 UAS Elements

The following UAS elements will be further investigated and specified^[105]:

- Aircraft (UA)
- Payloads
- Data Links, comprising:
 - Voice Communications Link (radio, ATC)
 - Data Communications Link (air vehicle command & control, payload control, air vehicle status and health)
 - Payload Data Link (acquired payload data)
- UA Recovery
- Ground Elements, including:
 - Ground Control Station, incorporating:
 - Aircraft Workstation (radio, ATC, command & control, status and health)
 - Payload Workstation (data reception, recording, manipulation, analysis, distribution)

- Launch
- Recovery
- Logistic Support, including:
 - Ground Power
 - Storage
 - Transportation

13.2. Conclusion

All of the elements up for discussion in this Chapter have some form of physical, functional or operational interaction, and cannot be viewed (or specified) in isolation. An integrated approach will be followed in the development of the concept specification for the various elements.

Chapter 14

14. Unmanned Aircraft

This Chapter provides a summary of key parameters describing the concept for the Unmanned Aircraft (the “Aircraft”). Parameters determined are basic weights, basic sizing and basic powerplant requirements. The intent of this chapter is not to provide results for a full-on design, but to develop an estimation and a “feel” for the size aircraft expected for such a mission.

Two methods were followed to obtain the results presented in this Chapter. Method 1 made use of the reference material “An Introduction to Experimental Light Aircraft Design”, First Edition, by Mr Anton Maneschijn^[109]. As this reference material focuses primarily on design for light and experimental aircraft, the method was used as a first-order iteration and to serve, in some respects, as input for Method 2.

Method 2 made use of the reference material “Aircraft Design – A Conceptual Approach”, Second Edition, by Mr Daniel P. Raymer^[110]. Although this reference provides very comprehensive material on Concept Design, including structures, performance, aerodynamics and trade studies, the aim of the thesis was only to determine basic parameters, and the results presented in this Chapter reflect this aim. Additional design effort shall be required to refine the design concept before Preliminary and Detail design studies commence.

This Chapter provides a summary of the key values derived. Details on how these values were derived are available in Appendices K and L.

14.1. Presentation

Results are presented along the following structure:

- Layout
- Weights
- Dimensions

- Powerplant
- Performance

Payloads are discussed in some detail in Chapter 15.

14.2. Layout

The purpose of the aircraft is to serve as a stable platform to carry the special mission equipment into and throughout the search area. Due to the nature of its mission and application, the aircraft will not be subjected to extreme manoeuvres (combat- or aerobatic), and therefore did not require such design features.

Aircraft configuration and layout is largely dependent on three factors: functional requirements, performance requirements and personal preference. Both design methods require the designer to select general layouts – position of wings, engines, etc – on commencement of design; the design process is largely dependent on the initial layout chosen. The layouts described below, as chosen for this concept, should not be regarded as the only solutions to meet the requirements. Many other design layouts and configurations, based on personal preference and experience, could be presented offering even better results. The layouts chosen serve to act as input for the two concept designs and offer potential solutions that will meet the requirements.

14.2.1. Layout: Design Method 1

Design Method 1 is based on a largely conventional layout. An initial comparison was made to find an existing aircraft having similar performance characteristics as those specified for this requirement. The Gulfstream G550 was found to be the quite close and was thus used as a basis and comparison throughout the concept design phase to validate the general layout for Method 1.

The aircraft as developed via Method 1 exhibits a centrally located, low mounted swept wing, a rear located, low mounted horizontal tail, a single rear located, centrally mounted vertical tail and tricycle landing gear. The

powerplant is located in two nacelle pods mounted on the rearward portion of the fuselage, behind the main wing, above the horizontal tail surface and both sides of the vertical tail. The nose contains the satellite communication equipment and nose landing gear. The FLIR sensor and Maritime Search Radar (MSR) are located in a faired conformal pod below the centre fuselage to reduce drag. Fuel is carried in the wings and in a centrally-located fuselage fuel tank. Deployable payloads (markers and canisters) are carried in the lower, rear fuselage portion to afford maximum release clearance.

14.2.2. Layout: Design Method 2

Design Method 2 is also based on a largely conventional layout. No initial comparisons were made with any specific existing aircraft; however Historical Data selected, as per the reference material^[110], matches data for commercial jet transport aircraft in general. The selection of layout and data for Method 2 stems primarily from the output of Method 1.

The aircraft as developed via Method 2 exhibits a centrally located, low mounted swept wing, a rear located T-tail and tricycle landing gear. The powerplant is located in two nacelle pods mounted on the rearward portion of the fuselage, behind the main wing and below the horizontal tail surface of the T-tail. The nose contains the satellite communication equipment and nose landing gear. The FLIR sensor and Maritime Search Radar (MSR) are located in a faired conformal pod below the centre fuselage to reduce drag. Fuel is carried in the wings and in a centrally-located fuselage fuel tank. Deployable payloads (markers and canisters) are carried in the lower, rear fuselage portion to afford maximum release clearance.

14.3. Weights

This sub-section summarises the basic weights derived from the two design methods.

14.3.1. Basic Weights: Design Method 1

Basic aircraft weights as derived from Design Method 1 are as follows:

- Maximum all-up (take-off) weight: 45,000 kg

- Maximum fuel weight: 27,334 kg
- Maximum payload weight (only deployable payloads): 1,400 kg
- Total powerplant weight (engines x 2, basic, dry): 3,266 kg

Additional weights are available in Appendix K.

14.3.2. Basic Weights: Design Method 2

Basic aircraft weights as derived from Design Method 2 are as follows:

- Maximum take-off weight: 64,700 kg
- Maximum fuel weight: 29,071.6 kg
- Maximum payload weight (includes fixed and deployable payloads, and avionics): 2,903 kg
- Zero-fuel weight: 35,628.4 kg
- Empty weight: 32,725.4 kg
- Total powerplant weight (engines x 2, basic, dry): 4,726.4 kg

14.4. Dimensions

This sub-section summarises the basic dimensions derived from the two design methods.

14.4.1. Dimensions: Design Method 1

Basic aircraft dimensions as derived from Method 1 are as follows:

- Length: 22 m
- Wing span: 27.57 m
- Wing area: 108.55 m²
- Wing Aspect Ratio: 7

- Wing root chord: 5.5 m
- Wing tip chord: 2.38 m
- Wing leading edge sweep angle: 27°
- Wing Lift Coefficient (C_{lmax}): 2
- Flap type: Fowler
- Horizontal tail span: 10.36 m
- Horizontal tail area: 25.56 m^2
- Horizontal tail Aspect Ratio: 4.2
- Vertical tail height (above fuselage): 4.06 m
- Vertical tail area: 8.91 m^2

Additional dimensions are available in Appendix K.

14.4.2. Dimensions: Design Method 2

Basic aircraft dimensions as derived from Method 2 are as follows:

- Length: 33.6 m
- Wing span: 27.77 m
- Wing area: 110.43 m^2
- Wing Aspect Ratio: 7.0
- Wing root chord: 6.46 m
- Wing tip chord: 1.49 m
- Wing leading edge sweep angle: 30°
- Wing quarter chord sweep angle: 27°

- Wing Mean Aerodynamic Chord: 4.5 m
- Wing Lift Coefficient ($C_{l_{max}}$): 2
- Flap type: Slotted
- Horizontal tail (T-tail) span: 10.6 m
- Horizontal tail area: 28.07 m²
- Horizontal tail Aspect Ratio: 4.0
- Vertical tail (T-tail) height (above fuselage): 4.56 m
- Vertical tail area: 17.34 m²
- Vertical tail Aspect Ratio: 1.2

Additional dimensions are available in Appendix L.

14.5. Powerplant

The design incorporates two engines, primarily for the following reasons^{[83][99]}:

- Two engines will provide sufficient thrust to achieve the required performance levels
- Two engines will provide additional redundancy and increase the chances of mission success, in the event of a single engine failure.
- The added redundancy will ensure the recovery of the aircraft in the event of a single engine failure.

14.5.1. Powerplant: Design Method 1

The engine selected for the concept design developed under Method 1 is the BMW/Rolls-Royce BR710. The selected engine exhibits the following performance properties (the values below are for a single engine):

- Maximum power at sea level: 65,610 N

- Maximum power at cruise altitude: 15,750 N
- Specific Fuel Consumption at sea level: 0.39 lb/lbf.h
- Specific Fuel Consumption at cruise altitude: 0.681 lb/lbf.h

Additional properties are available in Appendix K.

14.5.1. Powerplant: Design Method 2

The engine selected for the concept design developed under Method 1 is the International Aero Engines IAE V2500-A1. The selected engine exhibits the following performance properties (the values below are for a single engine):

- Maximum power at sea level: 111,205.5 N
- Maximum power at cruise altitude: 22,552.48 N
- Specific Fuel Consumption at sea level: 0.35 lb/lbf.h
- Specific Fuel Consumption at cruise altitude: 0.581 lb/lbf.h

Additional properties are available in Appendix L.

14.6. Performance

This sub-section summarises the basic performance values derived from the two design methods. Values are basic estimations, and refinement of these figures is only possible utilising more complex means, including additional concept design refinement, detail design methods, Computational Fluid Dynamics, wind tunnel testing and scale model testing

14.6.1. Performance: Design Method 1

In summary, the design delivers the following performance values, as determined from Method 1:

- Stall speed at sea level: 207 km/h
- Maximum speed at cruise altitude: 869 km/h

- Cruise speed at cruise altitude: 801 km/h
- Maximum range: 7,856 nmi
- Total endurance: 17 h
- Time to reach Search Extremities: 6.4 h (6 h 24 min)

Additional performance details are available in Appendix K.

14.6.2. Performance: Design Method 2

In summary, the design delivers the following performance values, as determined from Method 2:

- Stall speed at sea level: 252.37 km/h
- Maximum speed at cruise altitude: 961.82 km/h
- Cruise speed at cruise altitude: 864.88 km/h
- Maximum range: 7,487.73 nmi
- Total endurance: 18 h
- Time to reach Search Extremities: 6.0 h

Additional performance details are available in Appendix L.

14.3. Conclusion

This Chapter has produced the basic concept for the Unmanned Aircraft. Two methods were employed, both yielding satisfactory results in terms of meeting the previously-established key performance requirements. General aircraft layout, weights and dimensions have been established.

At first observation, the maximum take-off weight (MTOW)-to-payload-weight ratio appears high for an unmanned aircraft. However, the high MTOW values are understandable when considering the large quantities (and weight) of fuel required to sustain the high speeds across the vast ranges. The payloads are

relatively standard for maritime surveillance applications, and therefore standard in terms of weight, when considered in isolation.

As a final note, despite the very different approaches followed by the two design methods, it is interesting to note how similar the results are. Method 1 yields an aircraft similar in size and weight to a Gulfstream G550, while Method 2 yields an aircraft similar in size and weight to an Embraer E-190 or Airbus A319. It is therefore evident that an Unmanned Aircraft designed for this purpose will be fairly large^{[80][99]}, regardless the design method employed.

Chapter 15

15. Payloads

This section describes the concept for the payloads to be carried on board the Unmanned Aircraft. Payloads are group into fixed and deployable types.

15.1. Fixed Payloads

Fixed payloads encompass those that are not dispensable during the mission. For this concept, fixed payloads are limited to the following:

- Electro-optical Infrared (FLIR) sensor
- Maritime Search Radar (MSR)
- Search and Rescue Direction Finder (SAR DF)

As mentioned in Chapter 14, the FLIR sensor and MSR are located in a faired conformal pod below the centre fuselage. In order to cut drag and save fuel, particularly during the transit portions of flight, between the point of departure and the search location, the FLIR sensor shall be retractable into the conformal pod. The only portion of the SAR DF located on the external fuselage is the antenna. The antenna should be located optimally to locate distress signals emanating from locator transmitters. A full Antenna Placement Study is required to determine the best position for the antenna, but for the purposes of this design concept, it is located below the rear fuselage, behind the conformal pod.

Many FLIR sensors, radars and SAR Direction Finders are available as off-the-shelf units and would be ideal for this concept. For the purpose of this study, the following equipment has been selected, based on performance, weight, size, impact on local industry and general supportability:

- FLIR sensor: Denel Optronics LEO-III-HD Stabilised Turret Assembly, incorporating:
 - Thermal Imager

- High Definition colour and near-infrared TV camera
- Eye-safe laser rangefinder
- Laser illuminator
- Geo-pointing and Geo-location functions
- MSR: Thales Ocean Master maritime radar, incorporating:
 - Antenna Unit
 - Transmitter Unit
 - Exciter/Receiver/Processing Unit
- SAR DF. RhoTheta RT-600 (also referred to as SAR-DF 517)

15.2. Deployable Payloads

Deployable payloads are those kinds that are capable of being ejected, launched, dropped, thrown or deployed during the mission. The range of deployable payloads for this concept has been limited to the following:

- Marine Location Markers (MLM)
- Aid Life Supply Canisters (ALSC)

As mentioned in Chapter 14, all deployable payloads are located in the lower rearmost fuselage portion for this concept to afford maximum release clearance.

The Marine Location Marker (MLM) specified for this design is the La Croix D6060A2A 90 minute day & night marker, with the following capabilities:

- Smoke and light effects emitted and visible for 90 minutes, day and night
- Sea surface colouring effect emitted for 90 minutes and visible for up to 120 minutes

Aid Life Supply Canisters (ALSC) are usually customer-specified. For the purposes of this study, the ALSC shall be equipped with the following items:

- Life raft
- Life vests
- Thermal blankets
- Medical supplies
- Emergency Locator Transmitter
- Dry clothing and towels
- Food supplies

The design and configuration will be similar to the Life Support International SUR-3812-00 UNI-PAC air droppable life raft system.

Both the MLMs and ALSCs shall be capable of being air-dropped via launch tubes, exiting in the lower rear fuselage. The concept shall cater for numerous units, typically eight MLMs and six ALSCs.

Due to the unmanned nature of this concept, all deployable payloads are to be jettisonable remotely from the Ground Control Station.

15.3. Payload Weight

Weight is a potentially crippling property of airborne systems, and should be kept within the prescribed maximum limits so as not to incur performance restrictions. The total weight limit for all payloads for this concept is 1,400 kg (specified during the design process – refer Appendices K and L). The individual weight limits are specified as follows:

- FLIR sensor: 100 kg
- MSR: 100 kg
- Deployable Payloads: 1,200 kg

The weight of the SAR DF is negligibly small compared with that of the above mentioned systems, and is therefore not individually specified. It shall form part of the avionics package weight budget.

The payloads as specified for this concept weigh as follows:

- FLIR sensor: Denel Optronics LEO-III-HD
 - 45 kg (maximum, equipped with all sensor simultaneously)
- MSR: Thales Ocean Master
 - 85 kg (all units)
- MLM: La Croix D6060A2A
 - 9.9 kg each (excluding launcher)
 - 79.2 kg for total of eight units
- ALSC: As for Life Support International SUR-3812-00 UNI-PAC
 - 45.5 kg each (excluding launcher)
 - 273 kg for total of six units

The total weight for all payloads, as specified for this concept, adds up to 482.2 kg, which is far below the maximum limit. The weight of the ALSC is most variable, since the internal configuration may dictate a new design, resulting in a heavier configuration. However, even if each ALSC ends up weighing 100 kg, the total payload weight adds up to 809.2, which is still well within the specified limit.

15.4. Payload Dimensions

Payloads are carried aboard or inside the aircraft airframe, which has to be large enough to accommodate the payloads. The following provides a summary of the primary and/or critical dimensions for the selected payloads, to determine airframe capacity.

- FLIR sensor: Denel Optronics LEO-III-HD
 - Diameter: 500mm
 - Height: 523 mm
 - Retractable depth: 550 mm (maximum, into fairing/fuselage)
- MSR: Thales Ocean Master
 - Antenna Unit (sizeable to fit any radome, but typically
 - Width: 950 mm
 - Height: 626 mm
 - Transmitter Unit (w x h x d)
 - 389 x 280 x 446 mm
 - Exciter/Receiver/Processor (ERP) Unit (w x h x d)
 - 572 x 222 x 420 mm
 - PDB Unit (w x h x d)
 - 250 x 232 x 297 mm
- SAR DF: RhoTheta RT-600
 - Bearing Antenna
 - Diameter: 270 mm
 - Height: 185 mm
- MLM: La Croix D6060A2A
 - Diameter: 180 mm
 - Length: 877 mm

- ALSC: As for Life Support International SUR-3812-00 UNI-PAC
 - Diameter: 535 mm maximum
 - Length: 1070 mm

Considering each payload, and comparing the payload dimensions to the space required in and around the fuselage, the following deductions can be made:

- FLIR sensor: Denel Optronics LEO-III-HD
 - The depth of the faired conformal pod should be more than 550 mm to provide sufficient space for the LEO-III-HD sensor to retract when stowed. The width of the conformal pod should be more than 500 mm to provide space for the sensor diameter.
- MSR: Thales Ocean Master
 - The depth of the faired conformal pod should be more than 630 mm to provide sufficient space for the Ocean Master antenna unit. The width of the conformal pod should be more than 950 mm to provide space for the antenna. Ample space is provided inside the fuselage above the antenna unit for the Transmitter, ERP and PDB units.
- SAR DF: RhoTheta RT-600
 - Ample space is provided for the Bearing Antenna to be mounted below the fuselage, behind the main wing.
- MLM: La Croix D6060A2A
 - Sufficient space should be provided internally in the lower rearmost fuselage section to accommodate four MLMs in two rows (eight in total).
- ALSC: As for Life Support International SUR-3812-00 UNI-PAC

- Sufficient space should be provided internally in the lower rearmost fuselage section to accommodate three ALSCs in two rows (six in total).

15.5. Conclusion

The Unmanned Aircraft concept makes provision for three fixed and two deployable payload types. Two of the fixed payloads are carried in a conformal pod below the fuselage. The deployable payloads are carried, and jettisoned remotely, via internal launch tubes, behind the conformal pod in the lower rearmost fuselage section. It has been determined that the Unmanned Aircraft concept caters for all payload weights. Considering the size of the aircraft as developed and specified in Chapter 14, it is deduced that the concept comfortably caters for all payload dimensional limits.

Chapter 16

16. Data Links

This section describes the concept for the Data Link^[85]. Due to the absence of an onboard crew or pilot, all information sent to, and received from, the aircraft, must be relayed via a “wireless” Data Link. Data Links are typically grouped into line-of-sight (LOS) and beyond line-of-sight (BLOS)^{[68][92]}. LOS Data Links are only effective up to the radio horizon, approximately 150 – 200 km (80 - 110 nmi) from point of origin^[68]. Due to the extreme ranges to be covered by this aircraft, a BLOS Data Link will be essential^[94].

16.1. Data Link Functions

The primary functions of the Data Link for this concept will be to:

- Provide a voice communications link between flying crew/mission specialists and other aircraft, vessels and ground-based rescue personnel. This requires a low bandwidth up-down-link voice carrier in the Data Link, at the specified frequency range for voice communications.
- Provide a voice communications link between ground-based flight crew and air traffic control and other airborne traffic flight crews. This requires a low bandwidth up-down-link voice carrier in the Data Link, at the specified frequency range for ATC communications.
- Provide a data communications link between ground-based flight crew and aircraft for aircraft Command and Control purposes. This data is received by the aircraft and translated into flight parameters for the UA. This requires a low bandwidth up-link data carrier, at the specified frequency range for command, control and telemetry data.
- Provide a data communications link between the aircraft and ground-based flight crew for UA performance status and system health. The information is used by the flight crews and provides them with aircraft status – speed, altitude, attitude, position, outside air temperature,

equipment temperature, remaining fuel, engine parameters, general onboard system and equipment health, to name a few. This requires a low bandwidth down-link data carrier, at the specified frequency range for status and health data.

- Provide a data communications link between ground-based system operators/flight crew and aircraft for payload control. The data is received by the UA and is used to control the payloads. Parameters that can be sent include payload azimuth and elevation, search modes, recording modes, focus depth, amongst others. This requires a low bandwidth up-link data carrier, at the specified frequency range for payload control data.
- Provide a payload data stream between aircraft and ground-based system operators/flight crew and rescue coordinators. The data transmitted is typically medium- to high resolution images or video. This requires a medium- to high bandwidth down-link data carrier, at the specified frequency range for payload image data.

Appendix M provides a graphical representation of the typical communications scenario for a maritime Search and Rescue UAS.

16.2. BLOS Data Link Service

Various satellite services (military and commercial) are available for this function, depending on the coverage and bandwidth requirements. Common commercial satellite services typically operate in the L-Band^[85] (1 to 2 GHz) frequency range^[68]. The advantage of using such a service is that antenna directionality is less critical, ensuring a more confident and reliable link^[68]. The disadvantage is smaller bandwidth, resulting in slower data transfer rates (maximum of about 1Mbit/s)^{[68][71]}.

Many BLOS UAs utilise a Ku-Band^[85] satellite link, which operates in the 12 to 18 GHz frequency range^[68]. This requires greater attention to antenna and radome design and very precise antenna directionality, but offers much greater data transfer rates (up to 8 Gbit/s)^[68].

Besides antenna design, the greatest problem associated with Ku-Band satellite links is coverage, which is limited primarily to landmass in South Africa^[71]. Virtually no Ku-Band coverage is available out to sea, an essential requirement for this application. Currently, the two largest commercial satellite services on offer providing full coverage of the entire national maritime Search and Rescue Region are Inmarsat and Iridium^{[68][71]}.

Iridium is a complete Global coverage option, even providing coverage over large portions of the Polar Regions. However, this service is primarily voice-only, providing a very low bandwidth (speed) of between 2.4 and 10kbps^{[64][65]}. This may be sufficient for a Command & Control link, but will definitely be insufficient for transmission of near-real-time payload data (typically video).

Inmarsat's "SwiftBroadband" service provides voice and high-speed data simultaneously, at up to 432 kilobits per second per channel. The Inmarsat service provides coverage over the entire national maritime Search and Rescue Region, with the exception of the Polar Regions^[67].

To enable near-real-time transmission of payload image data to ground receivers, a higher-bandwidth satellite service is ideally required. Typical data rates required for high quality real-time video is in the order of 1.5 to 2 Mbit/s^[68]. Although the Inmarsat SwiftBroadband service data rate is only about one quarter of that required for high quality real-time video, it should be sufficient for near-real-time high quality images and low-quality video^[68]. New data compression technology currently under research has also provided excellent results with low-bandwidth data rates^[71]. In addition, intelligent autonomous detection systems could be employed, transmitting low-quality images until a potential target is spotted, where after it automatically switches over to high quality for detail identification^{[74][95][97]}. This saves on bandwidth usage and service cost.

16.3. Data Link Redundancy

Due to the critical nature of the Data Link, redundancy is essential. During take-off and landing, which requires secure links to ensure aircraft survival, a Line-of-Sight (LOS) Data Link is employed^[68]. This is a standard, non-satellite

microwave link, and employs an omni-directional antenna for take-off and landing, and a directional antenna for extended range flight up to the radio horizon. Handover between antennas usually takes place just after take-off and prior to landing. This link will provide voice- and essential command & control- and status data services between the UA and flying crew.

The LOS link operates up to the radio horizon, and is then handed over to either another LOS link (relay station), or the BLOS link. Two separate LOS Data Links will provide the required level of redundancy during take-off and landing.

In order to facilitate a BLOS Data Link, satellite communications is required^{[71][92][94]}. This requires^[68] a reliable satellite communications transmitter, receiver, diplexer, modem and antenna at both the ground station and onboard the UA, and a reliable satellite service.

As a backup to the high bandwidth Inmarsat service, to offer redundancy at BLOS ranges, it is proposed that a second, lower-cost low-bandwidth satellite service be operated in parallel. Typically, the Iridium service could be employed as the backup link, offering all functions MINUS the payload control data up-link and payload image data down-link^{[68][71]}. The Iridium service also operates in the L-Band frequency range (1 – 2 GHz)^{[64][65]}. The backup link serves as a means to recover and return the aircraft, in the event of loss of primary BLOS Data Link.

For additional reliability and redundancy, both primary and secondary links should be operational at all times. A selector automatically measures signal strength and determines which service to use. In the event of a loss of one of the services, the selector automatically switches over to the active service.

16.4. Conclusion

The airworthiness, safety and capacity of the UA to carry out and successfully complete its mission hinges strongly on the choice, ability and reliability of the Data Links employed. This UAS shall require both Line-of-Sight and Beyond-Line-of-Sight Data Links. For the purposes of this study, a dual redundant

LOS link is proposed for Line-of-Sight flight, while the Inmarsat SwiftBroadband service will be adopted for the primary BLOS Data Link, and the Iridium service for the secondary (backup) BLOS Data Link.

The above configuration should provide the required capability, as well as redundancy, to successfully complete a mission across the national maritime Search and Rescue Region.

As a final note on SATCOM antenna design, it should be noted that antenna design is in itself a very specialised field^{[68][71]}. The final selection of antenna type for an application such as this will only be possible following extensive design calculations and analysis, especially if a Ku-Band antenna is selected. To cater for all possibilities, this concept should be capable of accommodating either a large parabolic Ku-Band antenna, or a large flat phased-array L-Band antenna.

Chapter 17

17. UA Recovery

This Chapter describes the concept for the recovery of the aircraft in the event of a critical system failure or loss of Data Link.

17.1. Recovery Methods

Most Unmanned Aircraft are equipped with either an automatic recovery system (ARS), a flight termination system (FTS), or both. These systems are either activated manually from the Ground Control Station (human intervention) or automatically in the event of a critical system failure, upon reaching of an exception condition, or a loss of communications with the UA (Data Link loss)^[68]. The FTS is engaged in the event of a multiple engine failure. The primary function of the ARS is to ensure that the aircraft is recovered, while the primary function of the FTS is to ensure that the aircraft does not endanger the lives of third parties (people in the air or on the ground) in the event of a failure to recover the aircraft.

Data Links are often designed with added robustness or redundancy (multiple links) to ensure that a link loss is either of very short duration or does not occur. Similarly, critical systems are either duplicated, or designed to very high standards, to increase the reliability and reduce the chances of failure. However, if these measures fail, or are not in place, the ARS and/or FTS take control^{[87][104]}.

When activated, the ARS will turn the aircraft around and return it home via a safe route, pre-defined and pre-programmed prior to flight. Should this option fail, or not be available, the FTS activates and essentially performs three tasks:

- Steers the UA away from potential third party sources by relocating the UA to a safe holding area, pre-defined and pre-programmed prior to flight;
- Entering a pre-programmed loiter condition to burn off excess fuel;

- Activates the mechanism for the termination of flight.

ARS and FTS both effectively steer the aircraft away from potential harm to third parties, but only the first option ensures a safe recovery at home base. An automatic recovery could involve an automatic landing (if the airport and aircraft is so equipped) or manual re-establishment of the Data Link and a manual recovery.

Flight termination systems employ various methods to reduce kinetic energy, most notably emergency parachutes aided by airbags to cushion impact. An FTS usually results in at least minor UA damage.

17.2. Recovery System Concept

The following recovery mechanisms have been adopted for the ARS and FTS for this concept.

17.2.1. Automatic Recovery System

The ARS shall be designed to perform as follows:

- The ARS shall be designed to activate automatically following loss of both primary and secondary Data Links for a time period of more than 10 seconds^[68], or the failure of a critical navigational system.
- On activation, the ARS shall turn the UA around and return it to its point of departure, following a pre-determined and pre-programmed route.
- Should the data link be re-established during recovery, the ARS shall return the UA to its original flight path and disengage.
- Recovery at point of departure shall be (first option) via an automatic landing.
- As a second option, should the point of departure not be equipped with the necessary navigational aids to allow an automatic landing, the flight crew shall re-establish link with the UA and perform a manual recovery.

17.2.2. Flight Termination System

The FTS shall be designed to perform as follows:

- Upon failure to automatically recover the UA, the FTS shall engage and relocate the UA to a pre-defined and pre-programmed holding area;
- When this location has been reached, the FTS shall enter the UA into a pre-programmed loiter condition to burn off excess fuel;
- Once the desired fuel level has been reached, the FTS shall reduce the UA speed to just above stall and activate an emergency ballistic parachute to reduce kinetic energy. At the same time, the FTS shall cut power to the engines.
- The UA shall descend to the ocean surface.

By employing these methodologies, third parties are safeguarded from injury, and the UA is either returned and saved without loss or damage, or ditched with the likelihood of reduced damage and potential recovery at a later stage.

17.3. Conclusion

The means of recovery to be employed for this concept shall include both Automatic Recovery and Flight Termination. The ARS is the primary system, handing over to the FTS only if the ARS fails. The ARS shall return the UA to its point of origin, via a safe and pre-programmed route. The FTS shall steer the UA to a safe location via a pre-programmed route and terminate flight so as to minimise damage to the aircraft.

The ARS and FTS for this concept shall protect third parties from injury, while saving the UA.

Chapter 18

18. Ground Elements

This section describes the concept for the ground-based elements of the Unmanned Aircraft System. The ground elements are divided into the following sub-elements^[68]:

- Ground Control Station
 - Aircraft Workstation
 - Payload Workstation
- Launch
- Recovery
- Logistic Support Elements
 - Ground Power
 - Storage
 - Transportation

18.1. Ground Control Station

The Ground Control Station (GCS)^{[89][103]} effectively takes over the functions of the traditional aircraft cockpit and mission stations. It houses the crew and all means of interacting with the aircraft, other air traffic, vessels, rescue coordination centres and third parties during the mission^[68]. It also houses the Data Link transmission and reception equipment and systems.

In terms of function, and for the purposes of this concept, the GCS is split up into an Aircraft Workstation (AWS), a Payload Workstation (PWS) and a Mission Specialist Workstation (MSWS)^[68]. In reality, all these work areas are contained in one unit, and are co-located side-by-side to enhance interoperability and inter-communication.

18.1.1. Aircraft Workstation

The Aircraft Workstation (AWS) comprises all elements required for flight, tracking and command & control of the UA. It is used by ground-based flight crews to control, monitor and alter the flight path, and monitor and adjust performance of the UA before and during missions^[68].

Primary functions associated with the AWS include^[68]:

- Taxi, take-off and landing;
- Planning, programming and altering of flight path;
- Sense and Avoid;
- Manual flight;
- Monitoring of UA status and health;
- Communication with Air Traffic Control and other air traffic;
- Communication with vessels and sea surface search parties;
- Manual activation of Recovery or Flight Termination systems;
- Mission debrief.

Primary equipment in the AWS includes^[68]:

- Interface for flight path planning and programming;
- Primary flight display with map and overlays for situational awareness, flight path, flight planning, instruments and aircraft status;
- Secondary display with payload data video feed;
- Air Traffic Control radio equipment;

- Radio equipment (“tactical radios”) to communicate with vessels, rescue co-ordination centres and other organisations involved with the mission;
- Intercom to communicate with payload operators, mission specialists and other personnel in the GCS.

18.1.2. Payload Workstation

The Payload Workstation (PWS) is manned by payload controllers and data analysts. PWS equipment is used to control the onboard payloads and to receive, process and analyse payload data, to help guide the UA to those in distress^[68]. Payload controllers also eject essential dispensable payloads to aid those in distress, once located.

Primary functions associated with the PWS include^[68]:

- Payload selection and control;
- Target location;
- Target recognition;
- Target identification;
- Deployable payload operation.

Primary equipment in the PWS includes^[68]:

- Primary displays for radar operator and FLIR operator, each with the capability to overlay information from adjacent displays;
- Payload control interfaces;
- Data reception, processing and analysis equipment;
- Dispensable payload arming, disarming and ejecting equipment;

- Radio equipment (“tactical radios”) to communicate with vessels, rescue co-ordination centres and other organisations involved with the mission;
- Intercom to communicate with flight crews, mission specialists and other personnel in the GCS.

18.1.3. Mission Specialist Workstation

The Mission Specialist Workstation (MSWS) is manned by one or more rescue coordinators, whose primary function is to provide overall coordination between GCS crews and other organisations involved with the mission. They will interact with flight crews and payload operators, guiding them as the search unfolds or changes. Information is fed to them from the rescue coordination centres (RCCs) and other search parties, and is then passed on to relevant GCS crews and operators.

The MSWS will typically be equipped with tactical radios, telephones and intercom equipment for communicative purposes, as well as a data display for relaying of information to RCCs and other search parties.

18.2. Ground Control Station Layout and Ergonomics

Traditional UA ground control stations are often small and cramped, offering limited freedom of movement in and around the interior space. A compromise is often sought between comfort, size and weight. For military purposes, size and weight is of paramount importance, due air and ground mobility, footprint and visibility. This results in small crate-sized containers, with small interior space and little room for movement. Standard UAS control stations also usually only allow for two persons at a time: a UA pilot and a payload operator.

The Ground Control Station for this concept and application must cater for the following unique conditions:

- A larger complement of personnel at one time, typically:
 - 1x UA pilot

- 1x radar payload operator
- 1x FLIR payload operator
- 2x mission specialists (coordinators)
- Media observers
- Potentially extraordinarily long missions (up to 18 hours per UA, with handovers), requiring:
 - Comfortable and ergonomic working environment (seats and work stations);
 - An environment allowing frequent personnel changes, including mid-mission exchanges;
 - Lighting and air conditioning simulating natural conditions to reduce fatigue;
 - Simple, well defined and ergonomically designed user interfaces to allow fast, easy access to critical functions during peak mission activities;
 - Large, high definition colour screens for operators and crews;
 - Larger moving spaces within the GCS, allowing missions to be conducted without interruption during phases of peak activity or during personnel exchanges.

Due to the unique application of this UAS, the GCS should be designed with space and ergonomics as the driving factors, not reduced size and weight. The GCS for this application will be permanently located; mobility is therefore not an essential design constraint.

18.3. Launch

Due to the size and configuration of the UA, launch will be a conventional rolling take-off run from well-prepared runways.

Launches will be performed automatically (autonomous take-off) as the primary means^{[68][94][97][98]}, with manual intervention by flying crew (hands-on), as required or during emergencies.

18.4. Recovery

Recovery of the UA is a conventional landing on a well-prepared runway.

Recoveries will be performed automatically (autonomous landing) as the primary means^{[68][94][97][98]}. It is therefore essential that the operational airfield is equipped with an Instrument Landing System. In addition, recoveries can be performed manually by the flying crew (hands-on), as required or during emergencies.

18.5 Logistic Support

The total Logistic Support Package for the UAS includes, amongst others, ground power, maintenance and repair, spares, support vehicles, storage systems and transportation elements^[68]. The following aspects of Logistic Support will be looked at:

- Ground Power
- Storage
- Transportation

18.5.1 Ground Power

In cases where the national power supply is interrupted, emergency backup power must be available to power all ground systems, until the mission has ended. Backup power should be available to power at least:

- Ground Control Station
 - Aircraft Workstation
 - Payload Workstation
 - Mission Specialist Workstation

- Data Link elements

Backup power for this concept is to be supplied by means of a diesel generator, capable of providing sufficient power continuously for at least 120 hours.

18.5.2. Storage

Due to its size and weight, storage of the UA will be in standard airfield hangars. Deployable payloads are to be stored as per regulations for storage of pyrotechnic equipment. Ground elements are to be stowed and/or secured individually, as required.

18.5.3. Transportation

The concept behind the use of this system is built on the concept of a permanently located Ground Control Station, with permanently located Data Link and backup power elements. These elements will be permanently located at an airfield of choice, supplemented with UAs as required. The UAs will be stored in hangars at the airfield, and deployed when required for Search and Rescue missions. UAs will be “transported” between airfields by ferrying them by air. Should an aircraft become unserviceable prior to a ferry flight, spare parts will be brought to the airfield and the aircraft repaired and made serviceable.

18.6. Conclusion

The UAS comprises of numerous major ground elements. The concept of operations for the system necessitates that most of the system be permanently located at an airfield, equipped with a well-prepared, ILS-equipped runway and hangar facilities. The Ground Control Station, Data Link elements and backup power will be permanently located, with the aircraft itself operating from and stored at the said airfield.

Furthermore, it has been determined that the Ground Control Station design should centre on functionality, ergonomics and comfort, rather than mobility (size and weight), visibility and footprint.

Conclusions and Future Work

The following major Conclusions have been drawn from the Study.

- The oceans bordering Southern Africa are amongst the roughest, coldest and most hostile in the world. Persons in distress in such conditions do not stand a chance of survival, unless an effective and efficient Search and Rescue system, with highly specialised and capable assets, are on hand.
- Although the greater concentration of marine-related human activity takes place within the 200nmi Exclusive Economic Zone, activity is found across all national oceanic regions, and also well beyond our maritime borders and claims. Maritime Search and Rescue services should therefore be provided up to our defined maritime Search and Rescue Region extremities.
- South Africa has pledged to provide a world-class, effective, efficient, well-organised and professional Search and Rescue service within the full scope of its Search and Rescue Regions.
- The South African maritime Search and Rescue Region is one of the five largest worldwide, with a surface area in excess of 27 million square kilometres. Surface and airborne Search and Rescue assets are required to be available that can operate effectively and efficiently to the extremities of this region, a distance of more than 2800nmi from the nearest major port or airfield.
- The three common key performance elements for Search and Rescue assets are speed, range and endurance. A maritime Search and Rescue aircraft operating up to the limits of the national Search and Rescue Region will require a cruise speed of at least 466.7kn, a total endurance of at least 17 hours, and sufficient fuel to enable a total range of at least 7933.5nmi.

- Search and Rescue assets require special Search and Rescue equipment to enhance the chances of mission success. A maritime Search and Rescue aircraft operating across the very hostile national Search and Rescue Region will require at least FLIR, MSR, a SAR Direction Finder, Satellite Communications, Marine Location Markers and Aid Life Supply Canisters.
- Currently, no airborne SAR assets are available, domestically or internationally, manned or unmanned, to enable the execution of efficient and effective maritime SAR in the oceanic zone between 1800nmi and the 2800nmi Search Extremities.
- An Unmanned Aircraft should be ideal for long range maritime Search and Rescue.
- Long range maritime SAR aircraft exhibit high Maximum Take-off Weight-to-Payload Weight ratios. This is due to large fuel quantities required to satisfy the high performance requirements, versus technological advances offering small and light payloads.
- An Unmanned Aircraft for this purpose will be fairly large, regardless the design method employed.
- Fixed payloads should be retractable and/or located in a streamlined fairing to reduce drag. Deployable payloads should be located inside the fuselage in recessed launch tubes for the same reason, and capable of being deployed remotely.
- The airworthiness, safety and capacity of the UA to carry out and successfully complete its mission hinges strongly on the choice, ability and reliability of the Data Links employed.
- A long range maritime UAS shall require dual redundant Line-of-Sight and Beyond-Line-of-Sight Data Links.

- Emergency UA Recovery is essential in preventing injury to third parties as a first priority, while minimising damage to the aircraft as a second priority.
- A long range maritime UAS shall require an Automatic Recovery System, capable of returning the UA via a safe and pre-determined route, as well as a Flight Termination System, capable of steering the UA to a safe location and terminating flight so as to minimise damage to the aircraft.
- The concept of operations for an Unmanned Aircraft System for long range maritime SAR system requires most of the systems to be permanently located at an ILS-equipped airfield, with a well-prepared runway and hangar facilities. The Ground Control Station, Data Link elements and backup power should be permanently located, with the aircraft itself operating from and stored at the airfield. the Ground Control Station design should centre on functionality, ergonomics and comfort.

The following is regarded as Future Work, stemming from this Study.

- Refinement of the Unmanned Aircraft concept design;
- Determination of airspace requirements for the operation of this system in the National Airspace;
- Refinement of the Ground Control Station concept design;
- Refinement of the Logistic Support and additional ground support elements;
- Detailed study to determine precise Ground Control Station and support system placement;
- Study to determine and propose aircraft and support system availability, reliability and maintainability requirements;

- Determination of aircraft fleet.

PART 1

List of References

LIST OF REFERENCES

New Ref	Reference
1	Central Intelligence Agency. The World Factbook. <i>Coastline</i> . Available: https://www.cia.gov/library/publications/the-world-factbook/fields/2060.html
2	Department of Environmental Affairs and Tourism. Population and development. <i>Coastal cities</i> . Available: http://soer.deat.gov.za/indicator.aspx?m=216
3	Reference Answers. <i>Sea state</i> . Available: http://www.answers.com/topic/sea-state
4	Singleton, F. The Weather Window. <i>Sea waves, swells and other effects</i> . Available: http://weather.mailasail.com/Franks-Weather/How-Waves-And-Swell-Form
5	UK Meteorological Office. <i>Beaufort wind force scale</i> . Available: http://www.metoffice.gov.uk/weather/marine/guide/beaufortscale.html
6	World Meteorological Organization. 1995. WMO Code Tables, 1995 Edition, Part A, Section E: <i>Beaufort Scale of Wind</i> .
7	Piotrowski, M. 2010. Nautical Issues. Sailing & Marine Navigation. <i>Beaufort wind scale and Douglas sea scale</i> . Available: http://www.nauticalissues.com/en/beaufort.html
8	World Meteorological Organization. Marine Meteorology and Oceanography Programme. <i>Sea state and Beaufort scale</i> . Available: http://www.wmo.int/pages/prog/amp/mmop/faq.html
9	World Meteorological Organization. 1995. WMO Code Tables, 1995 Edition, Part A, Section C: Table 3700. <i>WMO Sea State Code</i>
10	De Jager, R. (Lt Col). 2010. South African Air Force, Directorate Air Transport & Maritime Systems, Staff Officer Maritime Operations. [Personal communication]. May 2010.
11	National Oceanic and Atmospheric Administration. National Oceanographic Data Center. Wavewatch III. <i>Significant Wave Height and Mean Wave Direction</i> . Available: http://www.nodc.noaa.gov/General/wave.html
12	National Oceanic and Atmospheric Administration. Oceanweather Inc. <i>South Atlantic, Significant Wave Height with Wave Direction</i> . Available: http://www.oceanweather.com/data/index.html
13	National Oceanic and Atmospheric Administration. Earth System Research Laboratory. <i>Scalar Wind</i> . Available: http://www.esrl.noaa.gov/psd/cgi-

New Ref	Reference
	bin/db_search/DBSearch.pl?Dataset=ICOADS+2x2+Degree+Enhanced+LTMs&Variable=Scalar+Wind
14	National Aeronautics and Space Administration. Ocean Motion and Surface Currents. <i>Wind Driven Surface Currents</i> . American Meteorological Society. Available: http://www.oceanmotion.org/html/background/wind-driven-surface.htm
15	National Aeronautics and Space Administration. Ocean Motion and Surface Currents. <i>Ocean Surface Currents</i> . OSCAR Project Office. Seattle, USA. Available: http://oceanmotion.org/html/resources/oscar.htm
16	Smith, R., Desflots, M., White, S., Mariano, A.J., Ryan, E.H. 2004. <i>The Antarctic CP Current</i> . Ocean Surface Currents.
17	Gyory, J., Beal, L.M., Bischof, B., Mariano, A.J., Ryan, E.H. 2004. <i>The Agulhas Current</i> . Ocean Surface Currents.
18	Gyory, J., Mariano, A.J., Ryan, E.H. 2004. <i>The Benguela Current</i> . Ocean Surface Currents.
19	Seed, P. 2008. <i>Ocean Currents and Tides: The Treacherous Agulhas</i> . Available: http://www.ruf.rice.edu/~feegi/ocean.html
20	Speer, K. 2008. International Polar Year. <i>Goodbye Agulhas Current; hello Roaring 40's</i> . Available: http://www.ipy.org/ipy-blogs/item/1423-fsu-ipy-cruise-says-goodbye-agulhas-current-hello-roaring-40s
21	Andersen, Egbert, Erofeeva and Ray. 2006. <i>Non-linear tides in shallow water regions from multi-mission satellite altimetry & the Andersen 06 Global Ocean Tide Model</i> . Presented AGU WPGM meeting, Beijing, China, July, 2006.
22	Locarnini, R.A., Mishonov, A.V., Antonov, J.I., Boyer, T.P., and Garcia, H.E. 2006. Temperature. <i>World Ocean Atlas 2005, Volume 1</i> . NOAA Atlas NESDIS 61, U.S. Government Printing Office, Washington, D.C
23	National Oceanic and Atmospheric Administration. Satellite and Information Service. <i>Sea Surface Temperature contour charts</i> . Available: http://www.osdpd.noaa.gov/ml/ocean/sst/contour.html
24	National Oceanic and Atmospheric Administration. Earth System Research Laboratory. <i>Air Temperature</i> . Available: http://www.esrl.noaa.gov/psd/cgi-bin/DataAccess.pl?DB_dataset=CDC+Derived+NCEP+Reanalysis+Products+Surface+Level&DB_variable=Air+Temperature&DB_statistic=Mean&DB_tid=24756&DB_did=39&DB_vid=1041
25	South African National Antarctic Programme. <i>Marion Island</i> . Available: http://www.sanap.org.za/sanap_marion/sanap_marion.html
26	South African National Antarctic Programme. <i>Marion Island</i> . Available: http://marion.sanap.org.za/
27	South African National Antarctic Programme. <i>Marion Island Climate</i> . Available: http://marion.sanap.org.za/waether.html
28	WFMZ-TV Weather. 2010. <i>Prevailing Westerlies</i> . Available: http://www.wfmz.com/weather/23050680/detail.html
29	World Meteorological Organization. Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology

New Ref	Reference
	(JCOMM). <i>Metareas</i> . Available: http://weather.gmdss.org/metareas.html
30	South African National Antarctic Programme. <i>Marion Island - Life at the base</i> . Available: http://www.sanap.org.za/sanap_marion/marion_life_at_the_base.html
31	Bremner, E. 2010. Transnet, National Ports Authority, Port of Cape Town. [Personal communication]. July 2010.
32	United Nations. 2009. United Nations Convention on the Law of the Sea (UNCLOS). <i>Maritime Space: Maritime Zones and Maritime Delimitation</i> . Available: Link: http://www.un.org/Depts/los/LEGISLATIONANDTREATIES/africa.htm
33	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994.
34	United Nations. 2004. United Nations Convention on the Law of the Sea. Bulletin 54, p 144. <i>Table of Maritime Claims</i> . New York, 2004.
35	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994, p 2 to 3, par 4 to 8
36	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994, p 2, par 4
37	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994, p 3, par 5
38	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994, p 3, par 6
39	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994, p 3, par 7
40	Kampfer, A.K., Capt (SAN). 2010. South African Navy, SA Navy Hydrographic Office. South African Maritime Boundaries, Mainland and Prince Edward Islands. [Personal communication]. July 2010.
41	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994, p 4, par 14
42	United Nations. 2010. United Nations Convention on the Law of the Sea. <i>Commission on the Limits of the Continental Shelf (CLCS)</i> . Available: http://www.un.org/depts/los/clcs_new/continental_shelf_description.htm
43	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994, p 6 to 17, schedule 3
44	United Nations. 2010. United Nations Convention on the Law of the Sea. <i>Commission on the Limits of the Continental Shelf (CLCS) – Continental Shelf, Article 76</i> . Available: http://www.un.org/depts/los/convention_agreements/texts/unclos/part6.htm
45	South African Navy. 2010. <i>The Importance of the Sea</i> . Available: http://www.navy.mil.za/aboutus/role/index.htm
46	South Africa. 1994. South African Maritime Zones Act, no 15 of 1994, p 3, par 8(3)(a) and (b)
47	United Nations. 2010. Food and Agriculture Organization. Fisheries and Aquaculture Department. <i>Fishery and Aquaculture Country Profiles – South Africa</i> . Available: http://www.fao.org/fishery/countrysector/FI-CP_ZA/en
48	National Oceanic and Atmospheric Administration. 2009. Ocean Service Education. <i>Upwelling</i> . Available:

New Ref	Reference
	http://oceanservice.noaa.gov/education/tutorial_currents/03coastal4.html
49	Department of Environmental Affairs and Tourism. 2010. Oceans and Coasts. <i>Commercial Fishing</i> . Available: http://www.environment.gov.za/
50	Froese, R. and Pauly, D. (Editors). 2010. FishBase. Version 09/2010. Available: http://www.fishbase.org
51	Sharples, J., Moore, C. M., Hickman, A. E., Holligan, P. M., Tweddle, J. F., Palmer, M. R. & Simpson, J. H. 2009. Internal tidal mixing as a control on continental margin ecosystems. <i>Geophysical Research Letters</i> , 36, L23603.
52	South Africa. 2007. South African Maritime Safety Agency (SAMSA). Annual Report, 2007, p 13
53	United Nations. 2010. Food and Agriculture Organization. Fisheries and Aquaculture Department. <i>Statistics</i> . Available: http://www.fao.org/fishery/statistics/en
54	Department of Environmental Affairs and Tourism. 2005. Oceans and Coasts. <i>Catch Information</i> . Available: http://www.deat.gov.za/
55	SAInfo reporter. 2008. South Africa Info. <i>Mining and minerals in South Africa</i> . Available: http://www.southafrica.info/business/economy/sectors/mining.htm
56	Department of Mineral Resources. 2010. <i>Mineral Information</i> . Available: http://www.dmr.gov.za/minerals/about_minerals.stm
57	Department of Energy. 2010. <i>Energy Sources</i> . Available: http://www.energy.gov.za
58	Department of Mineral Resources. 2008. <i>Mineral Statistics Tables 2008</i> .
59	Department of Minerals and Energy. 2008. Directorate Mineral Economics. Report R71/2008: <i>An Overview of South Africa's Titanium Mineral Concentrate Industry</i> , p 1, Introduction
60	Department of Minerals and Energy. 2008. Directorate Mineral Economics. Report R71/2008: <i>An Overview of South Africa's Titanium Mineral Concentrate Industry</i> , p 2, par 2.1
61	Department of Minerals and Energy. 2008. Directorate Mineral Economics. Report R71/2008: <i>An Overview of South Africa's Titanium Mineral Concentrate Industry</i> , p 3, par 2.1
62	Exxaro. 2010. Business operations, Sands. <i>KZN Sands</i> . Available: http://www.exxaro.com/content/ops/sands_kzn.asp
63	Exxaro. 2010. Business operations, Sands. <i>Namakwa Sands</i> . Available: http://www.exxaro.com/content/ops/sands_namaqua_sands.asp
64	Department of Minerals and Energy. 2008. Directorate Mineral Economics. Report R71/2008: <i>An Overview of South Africa's Titanium Mineral Concentrate Industry</i> , p 3 to 4, par 2.2

New Ref	Reference
65	Department of Minerals and Energy. 2007. Directorate Mineral Economics. Report R63/2007: <i>An Overview of South Africa's Zircon Industry and the Role of BEE</i> , p 1, Introduction and p 2, par 2.1
66	Department of Minerals and Energy. 2007. Directorate Mineral Economics. Report R63/2007: <i>An Overview of South Africa's Zircon Industry and the Role of BEE</i> , p iv, Abstract
67	De Beers Group. 2008. <i>Marine mining</i> . Available: http://www.debeersgroup.com/Exploration-and-mining/Mining-methods/Marine-mining/
68	De Beers Group. 2008. <i>Mining operations</i> . Available: http://www.debeersgroup.com/en/Exploration-and-mining/Mining-operations/
69	Mbendi Information Services. 2010. <i>Extraction of Crude Petroleum in South Africa</i> . Available: http://www.mbendi.com/indy/oilg/ogus/af/sa/p0005.htm#10
70	Madyibi, L., di Primio, R., Smith, G., Kuhlmann, G., and Anka, Z. 2009. Evidence of Petroleum System Evolution of the Southern Bredasdorp Basin, South Africa: A Multi-Dimensional Approach. <i>Search and Discovery</i> . September 22, 2009. Article #10197
71	Subramoney, J. 2007. <i>Energy Status in South Africa</i> . Department of Minerals and Energy presentation. NEET workshop. 20 February 2007
72	National Ports Authority. <i>South African Ports</i> . Available: http://www.transnetnationalportsauthority.net/
73	National Ports Authority. <i>The Port of Ngqura</i> . Available: http://www.transnetnationalportsauthority.net/NPA_port_of_ngqura.html
74	National Ports Authority. <i>Cape Town: Services</i> . Available: http://www.transnetnationalportsauthority.net/NPA_ports_cape_town_services.html
75	National Ports Authority. <i>Mossel Bay: Berths</i> . Available: http://www.transnetnationalportsauthority.net/NPA_ports_mossel_bay_berths.html
76	National Ports Authority. <i>Port Elizabeth: Services</i> . Available: http://www.transnetnationalportsauthority.net/NPA_ports_port_elizabeth_services.html
77	National Ports Authority. <i>East London: Berth lengths and draughts</i> . Available: http://www.transnetnationalportsauthority.net/NPA_ports_east_london_berths.html
78	National Ports Authority. <i>Durban: Functions</i> . Available: http://www.transnetnationalportsauthority.net/NPA_ports_durban_Functions.html

New Ref	Reference
79	National Ports Authority. <i>Richards Bay: Services</i> . Available: http://www.transnetnationalportsauthority.net/NPA_ports_richards_bay_services.html
80	Coetzer, J.A. (Mid). 2010. Letter: <i>Fleet Maintenance Support Facilities</i> . 13 July 2010. South African Navy.
81	National Center for Ecological Analysis and Synthesis. 2010. <i>A global map of human impacts to marine ecosystems, Impacts</i> . Available: http://ebm.nceas.ucsb.edu/GlobalMarine/impacts/transformed/jpg/shipping.jpg
82	National Geographic. 2010. State of the earth 2010. <i>Global Shipping Intensity</i> . Available: http://earthpulse.nationalgeographic.com/earthpulse/earthpulse-map
83	Solar Navigator. <i>The Suez Canal, 13th Port of Call – A Wonder of the Modern World</i> . Available: http://www.solarnavigator.net/suez_canal.htm
84	Sand, P. 2009. <i>Avoiding piracy by sailing round the Cape of Good Hope is a costly business</i> . Baltic and International Maritime Council. Available: https://www.bimco.org/en/Members/News/2009/2009/11/23_Avoiding_piracy.aspx
85	Suez Canal Authority. 2008. <i>Canal Characteristics</i> . Available: http://www.suezcanal.gov.eg/sc.aspx?show=12
86	Willis, B. 2001. <i>Supertankers</i> . Worsley School. Available: http://www.worsleyschool.net/science/files/supertanker/page.html
87	Lloyd's List. 2008. <i>Svitzer picks Cape of Good Hope over Suez</i> . 6 November 2008. Available: http://www.lloydslist.com/ll/news/svitzer-picks-cape-of-good-hope-over-suez/20017588018.htm
88	England, A. 2008. <i>The Suez Canal: the fastest route, even in a slowdown</i> . 16 December 2008. Available: http://www.ft.com/cms/s/0/3a7e768a-cb0a-11dd-87d7-000077b07658.html#axzz15kXFBVge
89	National Ports Authority. 2009. <i>Port Statistics, Financial Year 2008-2009</i> . Available: http://www.transnetnationalportsauthority.net/NPA_Port_statistics.html
90	Chasomeris, M. G. 2002. Trade and Industrial Policy Strategies 2002 Annual Forum. <i>South Africa's Seaborne Commerce, Trade Flows, Transport Costs and the Maritime Transport Policy Environment</i> . 2002, Muldersdrift
91	Mitropoulos, E. E. 2007. <i>Opening of Regional MRCC, South Africa</i> (Speech by Secretary-General of the International Maritime Organization) Cape Town, 16 January 2007
92	Bremner, E. (Capt). 2010. <i>Vessel Arrivals at South African Ports: January-December 2009</i> . July 2010. Transnet
93	Bremner, E. (Capt). 2010. <i>Summary of Cargo Handled at Ports of South Africa: January-December 2009</i> . July 2010. Transnet

New Ref	Reference
94	Bremner, E. (Capt). 2010. <i>TEU's: January-December 2009</i> . July 2010. Transnet
95	Transnet. 2009. <i>Transnet Annual Results 31 March 2009</i> . 24 June 2009
96	Chasomeris, M. G. 2002. Trade and Industrial Policy Strategies 2002 Annual Forum. <i>South Africa's Seaborne Commerce, Trade Flows, Transport Costs and the Maritime Transport Policy Environment</i> . 2002, Muldersdrift, p 1, Introduction
97	South African Navy. 2010. <i>Equipment</i> . Available: http://www.navy.mil.za/equipment/index.htm
98	South African Police Services. <i>Budget Vote 27 – Safety and Security</i> . Available: http://www.saps.gov.za/_dynamicModules/internetSite/newsBuild.asp?myURL=653
99	South African Tourism. 2008. <i>Annual Tourism Report</i> , p 5
100	South African Tourism. 2008. <i>Annual Tourism Report</i> , p 6, par 2.1
101	South African Tourism. 2008. <i>Annual Tourism Report</i> , p 8, par 2.2
102	South African Tourism. 2008. <i>Annual Tourism Report</i> , p 78, par 10.5
103	du Plessis, M. 2008. <i>Investigation of the Cruise Liner Industry</i> . Mitchell du Plessis Projects (Pty) Ltd presentation. 16 July 2008, slide 8
104	du Plessis, M. 2008. <i>Investigation of the Cruise Liner Industry</i> . Mitchell du Plessis Projects (Pty) Ltd presentation. 16 July 2008, slides 9 and 10
105	du Plessis, M. 2008. <i>Investigation of the Cruise Liner Industry</i> . Mitchell du Plessis Projects (Pty) Ltd presentation. 16 July 2008, slide 22
106	du Plessis, M. 2008. <i>Investigation of the Cruise Liner Industry</i> . Mitchell du Plessis Projects (Pty) Ltd presentation. 16 July 2008, slide 5
107	du Plessis, M. 2008. <i>Investigation of the Cruise Liner Industry</i> . Mitchell du Plessis Projects (Pty) Ltd presentation. 16 July 2008, slide 14
108	Burden, E., Quan, T. 2009. <i>Royal Caribbean International takes delivery of much anticipated Oasis of the Seas</i> . Miami, 28 October 2009. Available: http://www.oasisoftheseas.com/press-room.php
109	South Africa. 1996. Constitution of South Africa, 1996, par 200.2
110	South Africa. 2002. New Defence Act 42 of 2002, p 13, ch 3, par 18(b) and (d)
111	Airline Route Maps. <i>Africa</i> . Available: http://www.airlineroutemaps.com/
112	Lufthansa. 2010. <i>Flight information, Lufthansa's route network</i> . Available:

New Ref	Reference
	http://lufthansa.innosked.com/Default.aspx?lang_id=en&country=za
113	Malaysia Airlines. 2010. <i>Destinations, our routes</i> . Available: http://malaysiaairlines.innosked.com/(S(zossig45tfwlcofmnydqfj55))/default.aspx?show=MAP&FromMap=no
114	South Africa. Civil Aviation Regulations, Part 91, General Operating and Flight Rules, Subpart 4: Instruments and Equipment, par 91.04.27 – 91.04.29
115	South Africa. Civil Aviation Technical Standards, Part 91, Operating and Flight Rules, par 91.04.28 and 91.04.29
116	Shipwrecks of South Africa. 2009. <i>Shipwrecks of South Africa</i> . Available: http://www.sashipwrecks.com/
117	Shipwrecks of South Africa. 2009. <i>Shipwrecks of South Africa</i> . Available: http://www.sashipwrecks.com/
118	WhyGo South Africa. 2010. <i>Shipwreck coast</i> . Available: http://www.southafricalogue.com/shipwreck-coast
119	AirDisaster. 2008. <i>Accident database, South Africa</i> . Available: http://www.airdisaster.com/cgi-bin/search_keyword.cgi?search=south+africa
120	South African Civil Aviation Authority. 2010. <i>Aircraft accident reports 1998</i> . Available: http://www.caa.co.za/
121	South African Civil Aviation Authority. 2010. <i>Aircraft accident reports 2001</i> . Available: http://www.caa.co.za/
122	South African Civil Aviation Authority. 2010. <i>Aircraft accident reports 2002</i> . Available: http://www.caa.co.za/
123	South African Civil Aviation Authority. 2010. <i>Aircraft accident reports 2003</i> . Available: http://www.caa.co.za/
124	South African Civil Aviation Authority. 2010. <i>Aircraft accident reports 2006</i> . Available: http://www.caa.co.za/
125	Central Intelligence Agency. The World Factbook. <i>Land boundaries</i> . Available: https://www.cia.gov/library/publications/the-world-factbook/fields/2096.html
126	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 10, schedule 1, preamble
127	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, schedule 1, preamble
128	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, pp 10 to 13, schedule 1
129	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, schedule 1
130	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 14, schedule 1, annex, ch 2, par 2.1
131	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, schedule 1, annex, ch 2, par 2.1
132	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 16, schedule 1, annex, ch 3
133	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, schedule 1, annex, ch

New Ref	Reference
	3
134	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 14, schedule 1, annex, ch 2, par 2.3
135	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 19, schedule 1, annex, ch 5
136	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, schedule 1, annex, ch 2, par 2.3
137	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, schedule 1, annex, ch 5
138	South African Search and Rescue Organisation. <i>Origins of SASAR</i> . Draft National SAR Manual, Appendix A
139	South African Search and Rescue Organisation. <i>Who are we</i> . Available: http://www.sasar.gov.za/
140	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 3, par 4.(2)(a)
141	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 4, par 5.(8)
142	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 4, par 6.(1)(a)
143	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 4, par 6.(3)
144	South African Search and Rescue Organisation. <i>Constitution of the South African Search and Rescue Organisation</i> , p 1, preamble
145	South African Search and Rescue Organisation. <i>Constitution of the South African Search and Rescue Organisation</i> , p 4, article 5, par 5.1
146	South African Search and Rescue Organisation. <i>Constitution of the South African Search and Rescue Organisation</i> , p 4, article 5, par 5.2(b)
147	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 9, ch 1, section 1
148	International Maritime Organization. 2010. <i>Member States</i> . Available: http://www.imo.org/About/Membership/Pages/MemberStates.aspx
149	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, par 3(1) and 3(2)
150	International Civil Aviation Organization. 2010. <i>Contracting States</i> . Available: http://www.icao.int/cgi/statesDB4.pl?en
151	United Nations. 2010. United Nations Convention on the Law of the Sea. <i>Chronological list of ratifications of, accessions and successions to the Convention and the related Agreements as at 15 November 2010</i> . Available: http://www.un.org/Depts/los/reference_files/chronological_lists_of_ratifications.htm#The United Nations

New Ref	Reference
	Convention on the Law of the Sea
152	International Maritime Organization. 2010. <i>Conventions, SOLAS</i> . Available: http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-%28SOLAS%29,-1974.aspx
153	International Maritime Organization. 2010. <i>Conventions, Status of conventions</i> . Available: http://www.imo.org/About/Conventions/StatusOfConventions/Pages/Default.aspx
154	Southern African Development Community. 1995. Standing Maritime Committee. <i>Nodal points</i> . Available: http://www.navy.mil.za/SMC/nodal_points.htm
155	Southern Africa Development Community. 2002. <i>Organisation and co-operation</i> . Standing Maritime Committee of the Interstate Security and Defence Committee, p 1-1, ch 1, section 1006, par 1.a
156	International Hydrographic Organization. 2010. <i>IHO Member States</i> . Available: http://www.iho-ohi.net/english/home/about-the-iho/about-iho-member-states/ms-information.html
157	African Union. <i>Member States</i> . Available: http://www.africa-union.org/root/au/memberstates/map.htm
158	Southern Africa Development Community. 2010. <i>SADC Member States</i> . Available: http://www.sadc.int/
159	Southern Africa Development Community. 2010. <i>Policy on Politics, Defence and Security Cooperation</i> , Article 7, point 1. Blantyre, August 2001. Available: http://www.sadc.int/index/browse/page/157
160	Department of Foreign Affairs. 2004. <i>African Economic Community: History and present status</i> . Available: http://www.dfa.gov.za/foreign/Multilateral/africa/aec.htm
161	Sea Around Us Project. <i>Exclusive Economic Zones</i> . Available: http://www.seaaroundus.org/eez/
162	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 5, Foreword
163	Edwards, D. <i>Maritime and Aeronautical Search and Rescue Matters</i> . U.S. Coast Guard Search and Rescue, p 1
164	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 40, ch 6, par 1
165	Siko, M. 1996. <i>South Africa's Maritime Interest and Responsibilities</i> . Institute for Maritime Technology, p2
166	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 9, ch 1, Overview
167	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, Schedule 2, Search And Rescue, Annex 12 to the Convention on International Civil Aviation, ch 2, Organization, par 2.1.1.1
168	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 7, par 20(1)
169	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, par 20(1)

New Ref	Reference
170	International Civil Aviation Organization. <i>Support to NEPAD</i> . August 2004 to April 2005, p 2
171	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 14, annex, ch 2, par 2.1.2
172	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, annex, ch 2, par 2.1.2
173	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 23, ch 3, section 2.1.1
174	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 6, par 12(1)
175	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, par 12(1)
176	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 23, ch 3, section 1
177	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 20, ch 2, section 1
178	International Civil Aviation Organization. 1998. <i>Report of the ICAO/IMO Joint Working Group on Harmonization of Aeronautical and Maritime Search and Rescue</i> . Sixth ICAO/IMO Joint Working Group on SAR, Victoria, B.C., 5-9 October 1998
179	Edwards, D. <i>Maritime and Aeronautical Search and Rescue Matters</i> . U.S. Coast Guard Search and Rescue, p 2
180	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 17, annex, ch 3, par 3.1.6.1
181	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, annex, ch 3, par 3.1.6.1
182	South African Search and Rescue Organisation. <i>Operational and Reporting Procedures</i> . SASAR Policy Manual Vol 2, p 8, ch 1, par 1.1c
183	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 14, annex, ch 1, par 1.3.8
184	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 16, annex, ch 2, par 2.6.1
185	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, annex, ch 1, par 1.3.8
186	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, annex, ch 2, par 2.6.1
187	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 19, annex, ch 4, par 4.8.1
188	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, annex, ch 4, par 4.8.1
189	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 49, ch 8, section 3
190	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 18, ch 1, section 6.3.2
191	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 18, ch 1, section 6.3.1
192	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 21 and 22, ch 2, section 2.3.1 and 2.3.2
193	South African Search and Rescue Organisation. <i>Harbour Master's Areas of Responsibility (Maritime) SAR Region</i> .

New Ref	Reference
	Draft National SAR Manual, Appendix D
194	International Maritime Organization. 2010. <i>Conventions, International Convention on Maritime search and rescue</i> . Available: http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-on-Maritime-Search-and-Rescue-%28SAR%29.aspx
195	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 5, par 10(2)
196	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, par 10(2)
197	South African Search and Rescue Organisation. <i>Diagrammatical representation of SASAR's Search and Rescue Region</i> . Draft National SAR Manual, Appendix C
198	South African Search and Rescue Organisation. <i>Our regions</i> . Available: http://www.sasar.gov.za/regions/main.html
199	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 20, ch 1, section 2.2
200	United Nations. United Nations Atlas of the Oceans. <i>Shipping emergencies – search and rescue, SAR Convention</i> . Available: http://www.oceansatlas.com/unatlas/issues/emergencies/gmdss_sar/searchrescue.htm#_Toc515946374
201	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 16, ch 1, section 6.3
202	National Sea Rescue Institute. 2010. <i>About Us – Our History</i> . Available: http://www.nsri.org.za/about/
203	National Sea Rescue Institute. 2010. Available: http://www.nsri.org.za/new/Index.asp
204	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 25, ch 3, section 2.3.1
205	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 25, ch 3, section 2.3.1 (a) to (h)
206	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 24, ch 3, section 2.2.1
207	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 24, ch 3, section 2.2.1 (a) to (h)
208	South African Search and Rescue Organisation. <i>Draft National SAR Manual</i> , p 26, ch 3, section 2.4.1 (a) to (f)
209	Skycontrol Aviation & Aerospace News. <i>Transnet National Port Authority of South Africa Orders a Grand Helicopter for Harbour Pilot Shuttle Operations</i> . Available: http://www.skycontrol.net/helicopters/transnet-national-port-authority-of-south-africa-orders-a-grand-helicopter-for-harbour-pilot-shuttle-operations/
210	Acher Aviation. 2009. <i>Marine Pilot Service</i> . Available: http://www.acheraviation.com/?m=1
211	Titan Helicopter Group. <i>Offshore Operations</i> . Available: http://www.titanhelicopters.com/index.php?page_id=4
212	Titan Helicopter Group. <i>Our Fleet</i> . Available: http://www.titanhelicopters.com/index.php?page_id=11
213	South Africa. 2001. South African Maritime and Aeronautical Search and Rescue Bill, p 14, annex, ch 2, par 2.1.2.3
214	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, par 6(3)

New Ref	Reference
215	South Africa. 2002. South African Maritime and Aeronautical Search and Rescue Act, 44, 2002, annex, ch 2, par 2.1.2.3
216	South African Search and Rescue Organisation. <i>Constitution of the South African Search and Rescue Organisation</i> , p 4, article 5, par 5.2(e)
217	South African Search and Rescue Organisation. <i>Constitution of the South African Search and Rescue Organisation</i> , p 5, article 6, par 6.2
218	South African Search and Rescue Organisation Policy Manual Vol 2, Operational and Reporting Procedures, p 10, ch 1, par 1.4d,h
219	Keijer, D.S. (Lt Col). 2010. South African Air Force, Directorate Helicopter Systems, DHS Helicopter Planning. [Personal communication]. May 2010.
220	South African Aircraft Register. <i>Aviation Databases</i> . Available: http://www.avdex.co.za/saregister/index.asp
221	Acher Aviation. 2009. <i>Gallery</i> . Available: http://www.acheraviation.com/?m=4&idkey=540
222	United States Army. <i>Thermal Imaging</i> . Night Vision and Electronic Sensors Directorate. Available: http://www.nvl.army.mil/thermal.html
223	FLIR Systems. 2010. <i>EO/IR</i> . Available: http://www.gs.flir.com/eoir/
224	Wolff, C. <i>Radar Sets – Ocean Master</i> . Radar Tutorial. Available: http://www.radartutorial.eu/19.kartei/karte604.en.html
225	Rhotheta. 2010. <i>Search and rescue direction finders for airborne rescue missions</i> . Available: http://www.rhotheta.com/applications/sar_airborne-rescue.html
226	Rhotheta. 2009. <i>SAR & Law Enforcement Direction Finder, RT-600/SAR DF-517</i> (Brochure)
227	Ritter, D. 2000. <i>Equipped to Survive</i> . Available: http://www.equipped.org/uscgarsat.htm
228	Experimental Aircraft Info. 2010. <i>Aircraft Distress Beacons</i> . Available: http://www.experimentalaircraft.info/homebuilt-aircraft/avionics-emergency-locator-beacon.php
229	Inmarsat. 2009. <i>Classic services: coverage</i> . Available: http://www.inmarsat.com/Services/Aeronautical/Classic_Aero/Coverage.aspx?language=EN&textonly=False
230	Inmarsat. 2009. <i>Swift 64: coverage</i> . Available: http://www.inmarsat.com/Services/Aeronautical/Swift_64/Coverage.aspx?language=EN&textonly=False
231	Inmarsat. 2009. <i>SwiftBroadband: coverage</i> . Available: http://www.inmarsat.com/Services/Aeronautical/SwiftBroadband/Coverage.aspx?language=EN&textonly=False

New Ref	Reference
232	Inmarsat. 2009. <i>SwiftBroadband: Flexible IP connectivity</i> . Available: http://www.inmarsat.com/Services/Aeronautical/SwiftBroadband/default.aspx?language=EN&textonly=False
233	Inmarsat. 2009. <i>SwiftBroadband: High-speed, IP-based voice and data</i> . (Brochure)
234	Ferris, G. (Lt Col). 2010. South African Air Force, Directorate Technical Support Services, Staff Officer Armament Maintenance Capabilities. [Personal communication]. June 2010
235	Life Support International. 2010. <i>UNI-PAC, Air-Drop, Bombay</i> . Available: http://www.lifesupportintl.com/products/UNI_PAC_Air_Drop_Bombay-2641-257.html
236	Lutz, W. 2010. Denel Dynamics, UAV Systems. [Personal communication]. June 2010
237	Boatsafe. 2009. <i>Boat Safe this Spring or Fall- avoid Hypothermia</i> . Available: http://boatsafe.com/nauticalknowhow/hypothermia.htm
238	South African Air Force. 2006. <i>Analysis of Maritime Tasks within the RSA Waters</i> . Directorate Air Capability Planning. Nov 2006
239	Insitu. 2009. <i>ScanEagle</i> . (Brochure)
240	Wainman, C. K., Egypt, R. <i>Project Gentle- Progress report 3: Maritime Environmental Characterization of the African EEZ – A Quantitative Analysis</i> . Institute for Maritime Technology. October 2009
241	Withington, T. 2009. The devil is in the detail. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.5. Oct/Nov 2009.
242	Owen, W.F. 2009. Not all spin. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.6. Dec 2009 Jan 2010
243	Scott, R. 2010. Finding their sea legs at last. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no1. Feb/Mar 2010.
244	Apthorp, C. 2010. Small world. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no1. Feb/Mar 2010
245	Lake, D. 2010. Seeker 400 looks to broader horizons. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no5. Oct/Nov 2010
246	Parry, D. 2007. Unmanned Aircraft Systems Briefing: Coastmaster. <i>World Airnews</i> . Vol. 35, no.10. December 2007
247	Heitman, H.R. 2010. Patrolling Africa's Waters Part 1. <i>World Airnews</i> . Vol. 37, no.11. January 2010
248	Heitman, H.R. 2010. Patrolling Africa's Waters Part 2. <i>World Airnews</i> . Vol. 37, no.12. February 2010.
249	Hayward, K. (Prof). 2008. UAS and ISTAR. <i>Aerospace Professional</i> . December 2008
250	Powrie, R.S. (Lt Col). 2010. <i>A109 LUH Deck Landing Performance</i> . November 2010.

PART 2

List of References

LIST OF REFERENCES

New Ref	Reference
1	The Free Dictionary. 2010. <i>Unmanned Aerial Vehicle</i> . Available: http://www.thefreedictionary.com/unmanned+aerial+vehicle
2	Army Technology. 2010. <i>Term: Unmanned Aerial Vehicle</i> . Available: http://www.army-technology.com/glossary/unmanned-aerial-vehicle.html
3	Ministry of Defence. 2008. <i>Defence Standard 00-970 Part 9 - UAV Systems</i> . Issue 4, amendment 1. p 18
4	Délégation générale pour l'Armement. 2005. <i>UAV Systems Airworthiness Requirements (USAR)</i> . Version 3.0. January 2005. p 8. Book 1, Subpart A, 1 (b)
5	Maneschiijn, A. 2008. <i>Interim Policy for Unmanned Aircraft Systems in South Africa</i> . Second Draft, August 2008, p 9, par 2.1.2 (gg)
6	Federal Aviation Administration. 2005. <i>Unmanned Aircraft Systems Operations in the U.S. National airspace system-Interim operational Approval Guidance</i> . AFS-400 UAS Policy 05-01. September 2005. par 5
7	North Atlantic Treaty Organization. <i>Unmanned Aerial Vehicles Systems Airworthiness Requirements (USAR)</i> . STANAG 4671. 9 May 2007. p 11. Annex 1. Introduction: Glossary
8	Délégation générale pour l'Armement. 2005. <i>UAV Systems Airworthiness Requirements (USAR)</i> . Version 3.0. January 2005. p 8, Book 1, Subpart A, 1 (c)
9	Maneschiijn, A. 2008. <i>Interim Policy for Unmanned Aircraft Systems in South Africa</i> . Second Draft, August 2008, p 9, par 2.1.2 (ii)
10	Naughton, R. (Dr). 2002. <i>Remote Piloted Aerial Vehicles: An Anthology</i> . Available: http://www.ctie.monash.edu/hargrave/rpav_home.html#Beginnings
11	Yochim, J. A. (Maj). 1998. <i>The Vulnerabilities of Unmanned Aircraft System Common Data Links to Electronic Attack</i> . (Master of Military Art and Science - Thesis) Utah, Weber State University.
12	Pearson, L. <i>Developing the Flying Bomb</i> . Naval Air Systems Command
13	Parsch, A. 2005. <i>Dayton Wright/Kettering Liberty Eagle ("Bug")</i> . Designation Systems. Available: http://www.designation-systems.net/dusrm/app4/bug.html

New Ref	Reference
14	Naughton, R. (Dr). 2002. <i>The Aerial Target and Aerial Torpedo in Britain</i> . Available: http://www.ctie.monash.edu.au/hargrave/rpav_britain.html
15	Goebel, G. 2010. <i>The Aerial Torpedo</i> . Available: http://www.vectorsite.net/twcruz_1.html
16	Goebel, G. 2010. <i>Early US Target Drones</i> . Available: Website, Vectorsite, http://www.vectorsite.net/twuav_01.html
17	Parsch, A. 2005. <i>Early Missiles and Drones</i> . Designation Systems. Available: http://www.designation-systems.net/dusrm/app1/a-target.html
18	Goebel, G. 2010. <i>Modern US Target Drones</i> . Available: http://www.vectorsite.net/twuav_02.html
19	Goebel, G. 2010. <i>Decoys</i> . Available: http://www.vectorsite.net/twuav_06.html
20	Goebel, G. 2010. <i>US Battlefield UAVs (1)</i> . Available: http://www.vectorsite.net/twuav_07.html
21	Kosiak, S. Heeter, E. 1997. <i>Unmanned Aerial Vehicles – Current Plans and Prospects for the Future</i> . UAV History. July, 1997
22	Goebel, G. 2010. <i>Modern US Endurance UAVs</i> . Available: http://www.vectorsite.net/twuav_13.html
23	National Aeronautics and Space Administration. <i>Ikhana</i> . Dryden Flight Research Center. Available: http://www.nasa.gov/centers/dryden/aircraft/Ikhana/index.html
24	Goebel, G. 2010. <i>US Battlefield UAVs (2)</i> . Available: http://www.vectorsite.net/twuav_08.html
25	Goebel, G. 2010. <i>International Endurance UAVs</i> . Available: http://www.vectorsite.net/twuav_14.html
26	Goebel, G. 2010. <i>International Battlefield UAVs (2)</i> . Available: http://www.vectorsite.net/twuav_11.html
27	Goebel, G. 2010. <i>US Battlefield UAVs (3)</i> . Available: http://www.vectorsite.net/twuav_09.html
28	Goebel, G. 2010. <i>Miniature UAVs</i> . Available: http://www.vectorsite.net/twuav_17.html
29	Simba Aviation. 2009. <i>Unmanned Aerial-System Classification</i> . Available: http://www.unmanned-aerial-system.com/classification.html
30	Goebel, G. 2010. <i>International Target Drones</i> . Available: http://www.vectorsite.net/twuav_03.html
31	Merriam-Webster. 2010. <i>Reconnaissance</i> . Available: http://www.merriam-webster.com/dictionary/reconnaissance
32	Cambridge University Press. 2010. <i>Reconnaissance</i> . Available: http://dictionary.cambridge.org/dictionary/british/reconnaissance
33	Merriam-Webster. 2010. <i>Surveillance</i> . Available: http://www.merriam-webster.com/dictionary/surveillance
34	Cambridge University Press. 2010. <i>Surveillance</i> . Available: http://dictionary.cambridge.org/dictionary/british/surveillance
35	Goebel, G. 2010. <i>Secret US Reconnaissance Drone</i> . Available: http://www.vectorsite.net/twuav_05.html

New Ref	Reference
36	Goebel, G. 2010. <i>UCAVs</i> . Available: http://www.vectorsite.net/twuav_16.html
37	Goebel, G. 2010. <i>The Prehistory of Endurance UAVs</i> . Available: http://www.vectorsite.net/twuav_12.html
38	United States Coast Guard. 2009. <i>UAS Project Description</i> . Acquisition Directorate. Available: http://www.uscg.mil/acquisition/uas/projectdescription.asp
39	Goebel, G. 2010. <i>The NASA ERAST HALE UAV Program</i> . Available: http://www.vectorsite.net/twuav_15.html
40	Aerovironment. <i>Wasp 3 Micro Air Vehicle</i> . (Datasheet). Available: http://www.avinc.com/uas/small_uas/wasp/
41	Aerovironment. 2009. <i>Raven RQ-11B</i> . (Datasheet). Available: http://www.avinc.com/uas/small_uas/raven/
42	L3 Communications Geneva Aerospace. 2009. <i>Viking 400</i> . (Datasheet). Available: http://www.l-3com.com/bai/viking400.html
43	Denel Dynamics. 2007. <i>Seeker II UAV surveillance system</i> . (Datasheet). Available: http://www.deneldynamics.co.za/brochures/Broc0268_Seeker%20II%20External.pdf
44	Pioneer UAV Inc. <i>RQ-2 Pioneer</i> . (Datasheet). Available: http://www.uavforum.org/sys-aircraft.asp
45	AAI Corporation. <i>RQ-7 Shadow 200</i> . (Datasheet). Available: http://www.aaicorp.com/products/uas/shadow_family.html
46	Northrop Grumman. <i>MQ-8B Fire Scout</i> . (Datasheet). Available: http://www.as.northropgrumman.com/products/p6mq8bfirescout/index.html
47	INSITU. 2009. <i>ScanEagle</i> . (Datasheet). Available: http://www.insitu.com/scaneagle
48	General Atomics. 2007. <i>MQ-1 Predator</i> . (Datasheet). Available: http://www.ga-asi.com/products/aircraft/predator.php
49	General Atomics. 2009. <i>Sky Warrior</i> . (Datasheet). Available: http://www.ga-asi.com/products/aircraft/er-mp-uas.php
50	Israel Aerospace Industries. 2006. <i>Heron 1</i> . (Datasheet). Available: http://www.iai.co.il/18900-16382-en/BusinessAreas_UnmannedAirSystems_HeronFamily.aspx?btl=1
51	Denel Dynamics. 2007. <i>Bateleur Medium-Altitude Long- Endurance Surveillance UAV</i> . (Datasheet). Available: http://www.deneldynamics.co.za/
52	General Atomics. 2007. <i>Predator B/ MQ-9 Reaper</i> . (Datasheet). Available: http://www.ga-asi.com/products/aircraft/predator_b.php
53	Northrop Grumman. 2005. <i>RQ-4A Global Hawk</i> . (Datasheet). Available: http://www.as.northropgrumman.com/products/ghrq4b/index.html
54	Israel Aerospace Industries. <i>Heron TP</i> . (Datasheet). Available: http://www.iai.co.il/18900-37204-en/BusinessAreas_UnmannedAirSystems_HeronFamily.aspx?btl=1

New Ref	Reference
55	Airforce Technology. 2010. <i>X-45 J-UCAV Joint Unmanned Combat Air System, USA</i> . Available: http://www.airforce-technology.com/projects/x-45-ucav/specs.html
56	Northrop Grumman. 2009. <i>X-47B Navy UCAS</i> . (Datasheet). Available: http://www.as.northropgrumman.com/products/nucasx47b/index.html
57	Dassault Aviation. 2006. <i>nEURON, A technological challenge</i> . Available: http://www.dassault-aviation.com/en/defense/neuron/a-technological-challenge.html?L=1
58	Littmann, E. 2003. <i>Unmanned Aerial Vehicles – Key to Intelligence</i> . European Aeronautic Defence and Space presentation. EADS International Technology Days. 4 and 5 November 2003. Slide 3
59	Kosiak, S. Heeter, E. 1997. <i>Unmanned Aerial Vehicles – Current Plans and Prospects for the Future</i> . Advantages and Disadvantages of UAVs. July, 1997
60	Kane, M. 2007. <i>Autonomous Systems and Future Capability</i> . BAE Systems presentation. Analysts/Fund Managers Visit. April 2007.
61	Mearns, S., Marshall, J. 2006. BAE Systems unveils the latest generation of autonomous air vehicles. <i>BAE Systems News Releases</i> . 30 March 2006
62	Air Attack Military Aviation News and Media. <i>BAE Corax UCAV</i> . Available: http://www.air-attack.com/page/74/BAE-Corax-UCAV.html
63	Maneschijn, A. 2008. <i>Interim Policy for Unmanned Aircraft Systems in South Africa</i> . Second Draft, August 2008, p 29 to 32
64	Iridium Communications. <i>The rate of speed for each Iridium Data Service</i> . Iridium Support. Available: http://www.iridium.com/Support.aspx
65	Iridium Communications. <i>Coverage Maps</i> . Support Library. Available: http://www.iridium.com/support/library/CoverageMaps.aspx
66	Inmarsat. 2009. <i>Aeronautical Services</i> . Available: http://www.inmarsat.com/Services/Aeronautical/default.aspx?language=EN&textonly=False
67	Inmarsat. 2009. <i>SwiftBroadband: coverage</i> . Available: http://www.inmarsat.com/Services/Aeronautical/SwiftBroadband/Coverage.aspx?language=EN&textonly=False
68	Lutz, W. 2010. Denel Dynamics, UAV Systems. [Personal communication]. June 2010
69	Hawkes, D., Mardiné, G., Allouche, M. 2008. <i>Unmanned Aircraft Systems, EUROCAE Activities</i> . EUROCAE

New Ref	Reference
	presentation. February 2008
70	Jackson, D. 2010. Denel Dynamics, UAV Systems. [Personal communication]. June 2010
71	De Beer, T. 2010. Denel Dynamics, UAV Systems. [Personal communication]. June 2010
72	la Franchi, P. 2009. Australia confirmed as MDA's second ISR customer. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.5. Oct/Nov 2009
73	Gourley, S.R. 2009. Green machines. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.5. Oct/Nov 2009
74	la Franchi, P. 2009. ICAO to standardize 'pilot' terminology for UAS. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.5. Oct/Nov 2009
75	Lake, D. 2010. The right mix. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.6. Dec 2009/Jan 2010
76	Henderson, A. 2010. A promising year ahead?. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.6. Dec 2009/Jan 2010
77	Ripley, T. 2010. Building the ISTAR hub. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.6. Dec 2009/Jan 2010
78	Owen, W.F. 2010. Not all spin. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.6. Dec 2009/Jan 2010
79	Withington, T. 2010. Power of the signal box. <i>Shephard's Unmanned Vehicles</i> . Vol.14, no.6. Dec 2009/Jan 2010
80	Owen, W.F. 2010. Facing the near future. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.1. Feb/Mar 2010
81	Apthorp, C. 2010. Small world. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.1. Feb/Mar 2010
82	Lake, D. 2010. Looking for lift. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.2. Apr/May 2010
83	Lake, D. Owen, W.F. Gourley, S.R. 2010. MALE contenders. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.2. Apr/May 2010
84	Lake, D. 2010. Oceans of potential. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.2. Apr/May 2010
85	Baddeley, A. 2010. Touching base. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.2. Apr/May 2010
86	Batey, A. 2010. The UAV commander. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.2. Apr/May 2010
87	Cantlie, J. 2010. The UAV pilot. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.2. Apr/May 2010
88	Lake, D. 2010. Seeing the future. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.3. Jun/Jul 2010
89	Apthorp, C. 2010. Pooling information. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.3. Jun/Jul 2010
90	Batey, A. 2010. Brothers in arms. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.3. Jun/Jul 2010
91	White, A. Ackerman, J. 2010. UAV's: the sky's the limit. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.4. Aug/Sep 2010
92	Lake, D. 2010. Seeker 400 looks to broader horizons. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.5. Oct/Nov 2010
93	White, A. 2010. Joined-up thinking. <i>Shephard's Unmanned Vehicles</i> . Vol.15, no.5. Oct/Nov 2010

New Ref	Reference
94	Parry, D. 2007. Unmanned Aircraft Systems Briefing: Autonomous Performance. <i>World Airnews</i> . Vol.35, no.10. Dec 2007
95	Holden, H. M. 2008. UAV Technology – Transitioning to the Civilian Market. <i>World Airnews</i> . Vol.36, no.1. March 2008
96	World Airnews. 2008. UAV Systems under the Spotlight. <i>World Airnews</i> . Vol.36, no.5. July 2008
97	Parry, D. 2008. UAS Review – The Farnborough Effect: Dassault Aviation. <i>World Airnews</i> . Vol.36, no.7. Sep 2008
98	Parry, D. 2008. UAS Review, Watchkeeper. <i>World Airnews</i> . Vol. 36, no.8. Oct 2008
99	Heitman, H.R. 2010. Patrolling Africa's Waters Part 2. <i>World Airnews</i> . Vol. 37, no.12. Feb 2010
100	Robinson, T. 2009. Wings clipped: airforces search for UAV non-pilots. <i>Aerospace International</i> . April 2009
101	Read, B. 2009. The sky's the limit. <i>Aerospace International</i> . Oct 2009
102	Robinson, T. 2009. Opening the skies. <i>Aerospace International</i> . Sep 2009
103	Gardner, R. 2009. Embracing the Xbox generation. <i>Aerospace International</i> . Sep 2009
104	Whitehouse, R. 2010. Unlocking the civil UAV market. <i>Aerospace International</i> . Sep 2010
105	Hayward, K. (Prof). 2008. UAS and ISTAR. <i>Aerospace Professional</i> . Dec 2008
106	Bratby, M. 2010. UAVs: Past, Present and Future. <i>Aerospace Professional</i> . Sep 2010
107	Ingham, L.A. <i>State of UAV Regulations in South Africa</i> . University of Stellenbosch Presentation
108	Maneschijn, A., Jones, T., von Backstrom, T.W., Ingham, L. A. A proposed reference framework for unmanned aerial vehicle and system airworthiness requirements. <i>The Aeronautical Journal</i> . June 2007
109	Maneschijn, A. 1990. <i>An Introduction to Experimental Light Aircraft Design</i> . First Edition. Anma Aviation. Kempton Park, 1990.
110	Raymer, D.P. 1992. <i>Aircraft Design – A Conceptual Approach</i> . Second Edition. American Institute of Aeronautics and Astronautics. Washington, D.C. 1992.

PART 1

Appendices

Appendix A

A. Oceanographic Characteristics

This Appendix provides a collection of oceanographic data pertaining to the oceanic regions bordering Southern Africa.

A.1. Sea States and Wave Height

The Sea State is a consolidated figure^{[3][4][250]} which takes into account wind, wave height, period, swell size and general character at a certain time and place. A number of scales^{[3][5][6][7][8][9]} are used to depict Sea State, the most common being the Beaufort Scale, Douglas Sea Scale, Pierson-Moskowitz Scale and the World Meteorological Organization (WMO) Sea State Code. Table A.1 presents various Sea States and equivalent wave height and oceanic characteristics as per the WMO Sea State Code.

Sea State Code	Significant Wave Height (m)	Characteristics
0	0	Calm (glassy)
1	0 to 0.1	Calm (rippled)
2	0.1 to 0.5	Smooth (wavelets)
3	0.5 to 1.25	Slight
4	1.25 to 2.5	Moderate
5	2.5 to 4	Rough
6	4 to 6	Very rough
7	6 to 9	High
8	9 to 14	Very high
9	Over 14	Phenomenal

Table A.1: World Meteorological Organization Sea State Code

The following figures^[10] provide a visual reference for Sea States, with accompanying surface wind speed in knots. Sea States 1 to 10 are depicted.

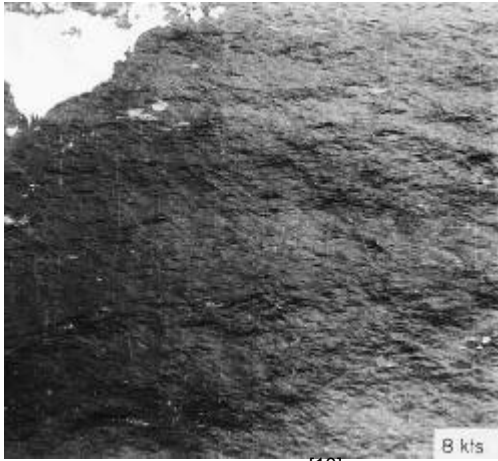


Figure A.1: Sea State 1^[10]

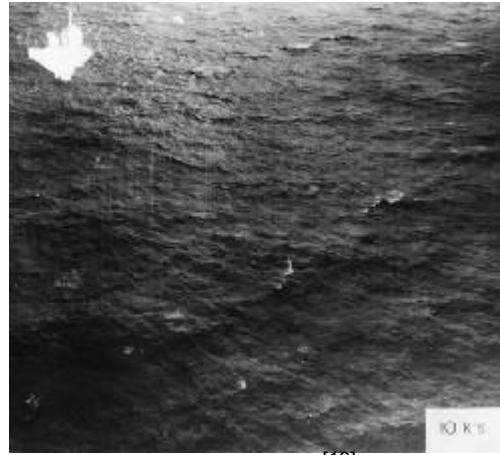


Figure A.2: Sea State 2^[10]



Figure A.3: Sea State 3^[10]



Figure A.4: Sea State 4^[10]



Figure A.5: Sea State 5^[10]

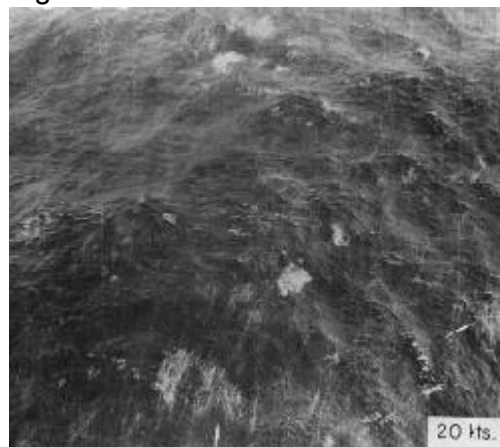


Figure A.6: Sea State 6^[10]



Figure A.7 Sea State 7^[10]



Figure A.8 Sea State 8^[10]



Figure A.9 Sea State 9^[10]

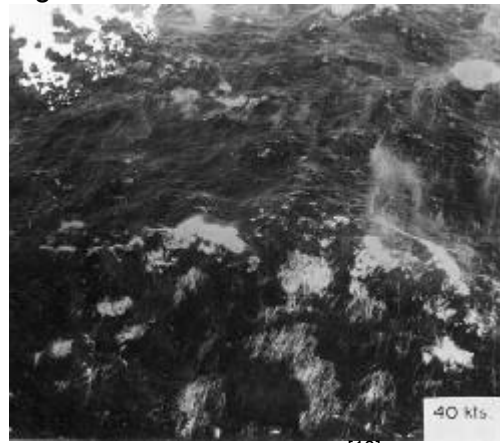
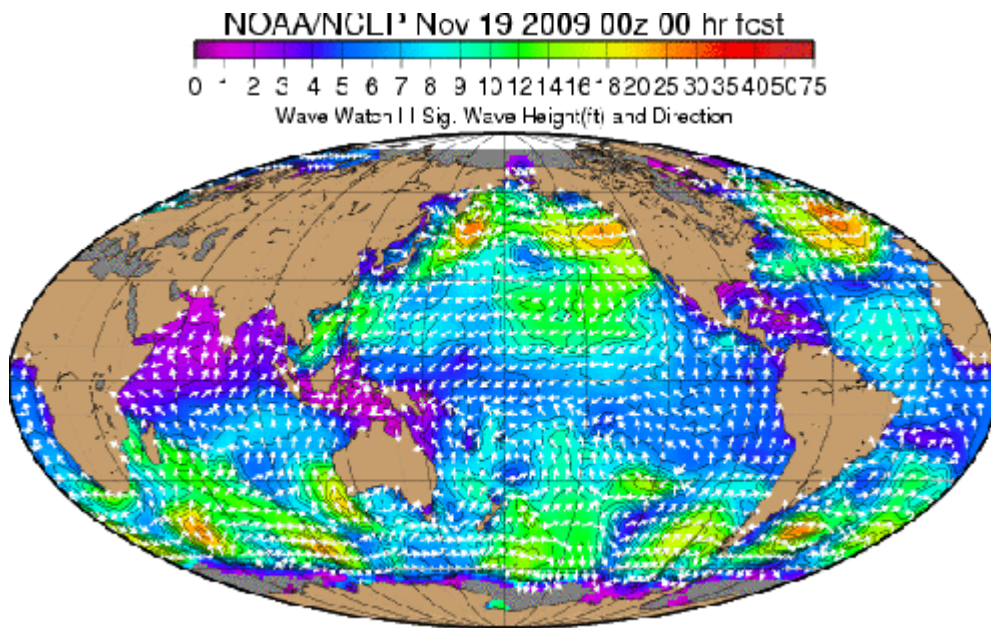


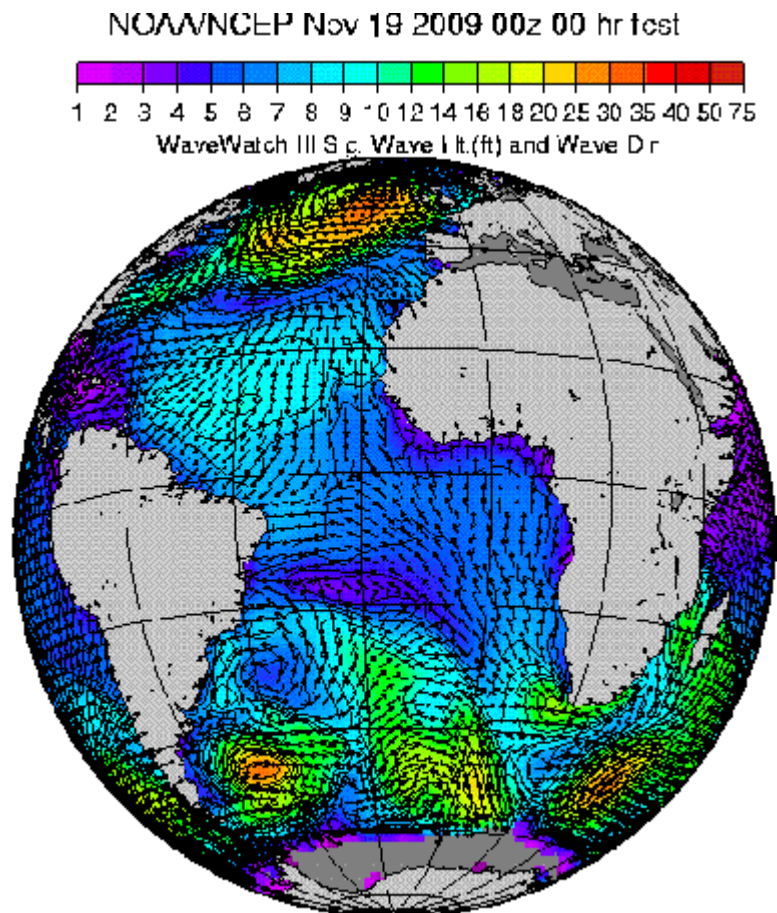
Figure A.10 Sea State 10^[10]

Figure A.11 shows the Worldwide significant Wave Height measured and analysed using the National Oceanic and Atmospheric Administration's (NOAA) Wavewatch III program, as on 19 November 2009^[11]. Figure A.12 shows the same analysis for the South Atlantic, on the same day. Areas around the Cape and in the seas between Africa and Antarctica are clearly in the yellow to orange bands, confirming that these are among the roughest in the World. Reference 240 provides additional information regarding Sea States for the national EEZ for Summer and Winter months, measured between 2005 and 2009, substantiating the former^[240].



NOAA Nov 19 00 2009 00z 00 hr fcst <http://www.ndbc.noaa.gov/>

Figure A.11: Significant Wave Height, Global, 19 November 2009^[11]



NOAA Nov 19 00 2009 00z 00 hr fcst <http://www.ndbc.noaa.gov/>

Figure A.12: Significant Wave Height, South Atlantic, 19 November 2009^[11]

Figure A.13^[12] indicates that the Wave Height measured in the seas around the Cape Peninsula and the Southern Oceans reaches 7 to 8 meters on a typical Summers day (19 November 2009). Further out to sea, beyond the Continental Shelf, the Wave Height reaches well beyond 8 meters, even as high as 9 meters in places, confirming the NOAA graphs.

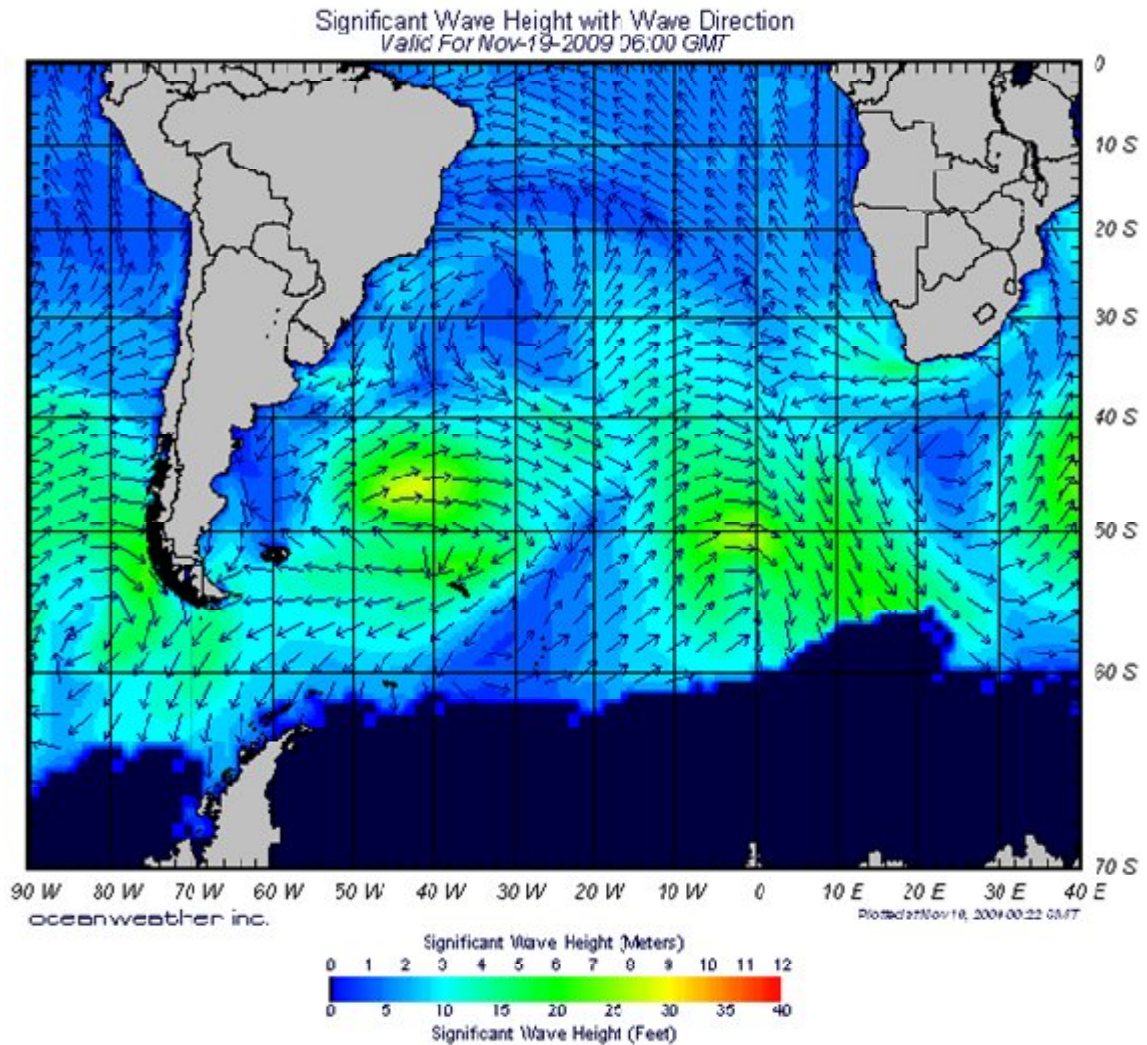


Figure A.13: Significant Wave Height, 19 November 2009^[12]

Reference 240 provides additional information regarding Wave Height for the national EEZ for Summer and Winter months, measured between 2005 and 2009, substantiating the former^[240].

A.2. Wind Speed

Figures A.14 and A.15 below^[13] (retrieved from the NOAA website subsidiary, National Climatic Data Centre, Marine Data) provide a graphical presentation of the average Annual Global and Southern African wind speeds measured at sea level. Yellows, oranges and reds indicate the highest speeds. From these graphs it is clear that, although coastal conditions appear moderate, average wind speeds between South Africa and Antarctica are above 11.0 meters per second, some of the highest in the World.

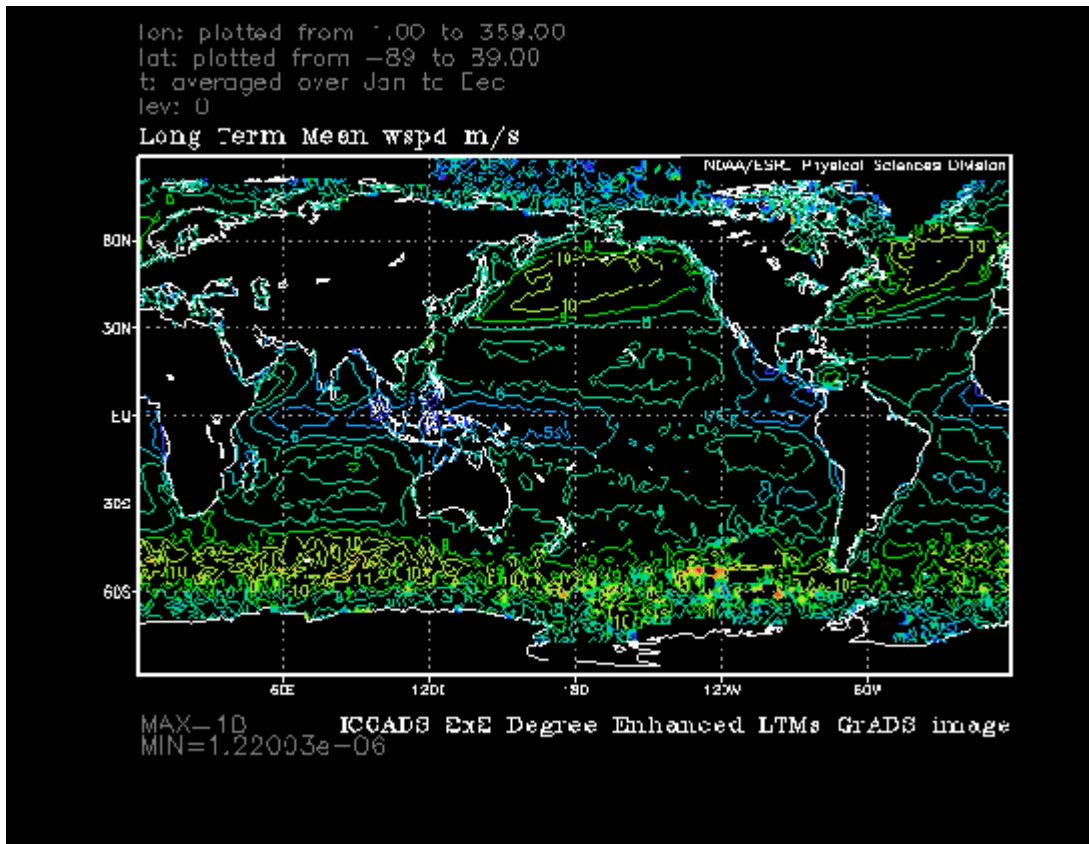


Figure A.14: Global Annual Sea Level Wind Speed (Averaged)^[13]

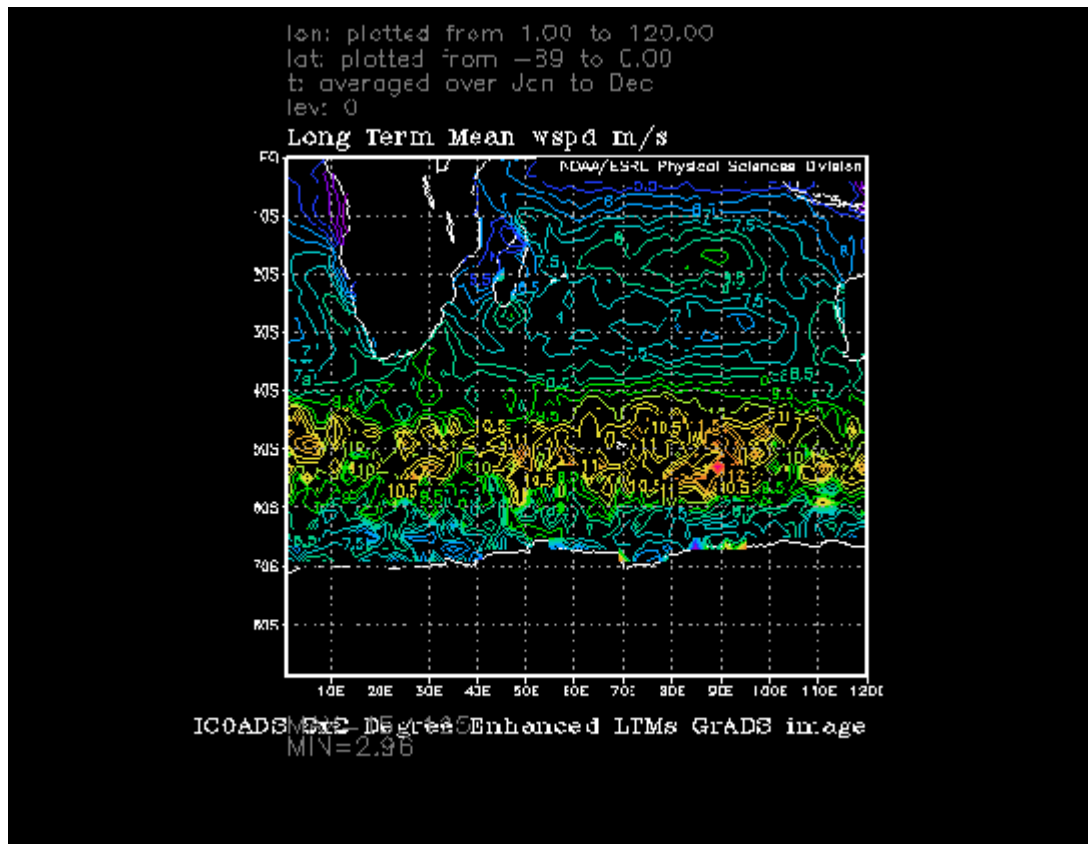


Figure A.15: Southern African Annual Wind Sea Level Speed (Averaged)^[13]

Reference 240 provides additional information regarding Wind Speed across the national EEZ for Summer and Winter months, measured between 2005 and 2009, substantiating the former^[240].

A.3. Oceanic Currents

Figure A.16 provides a diagrammatical illustration^[14] of Ocean Currents around the Globe.

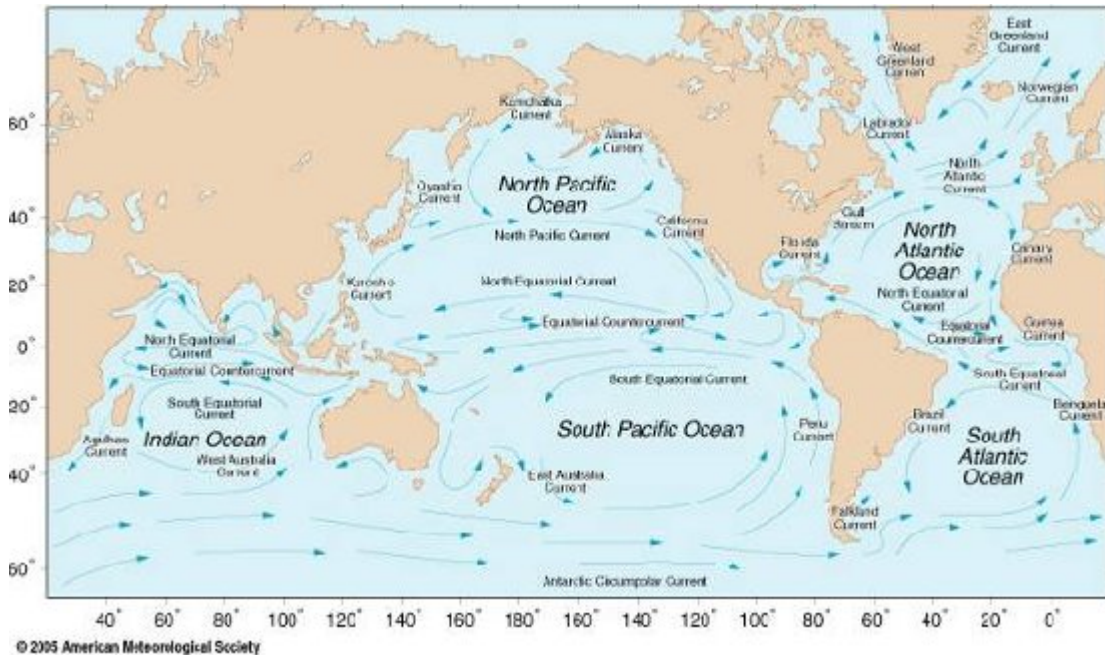


Figure A.16: Global Oceanic Wind-driven Surface Currents^[14]

Southern Africa is bordered by three main ocean currents: Antarctic Circumpolar, Agulhas and Benguela. Figure A.17 provides a graphical representation^[15].

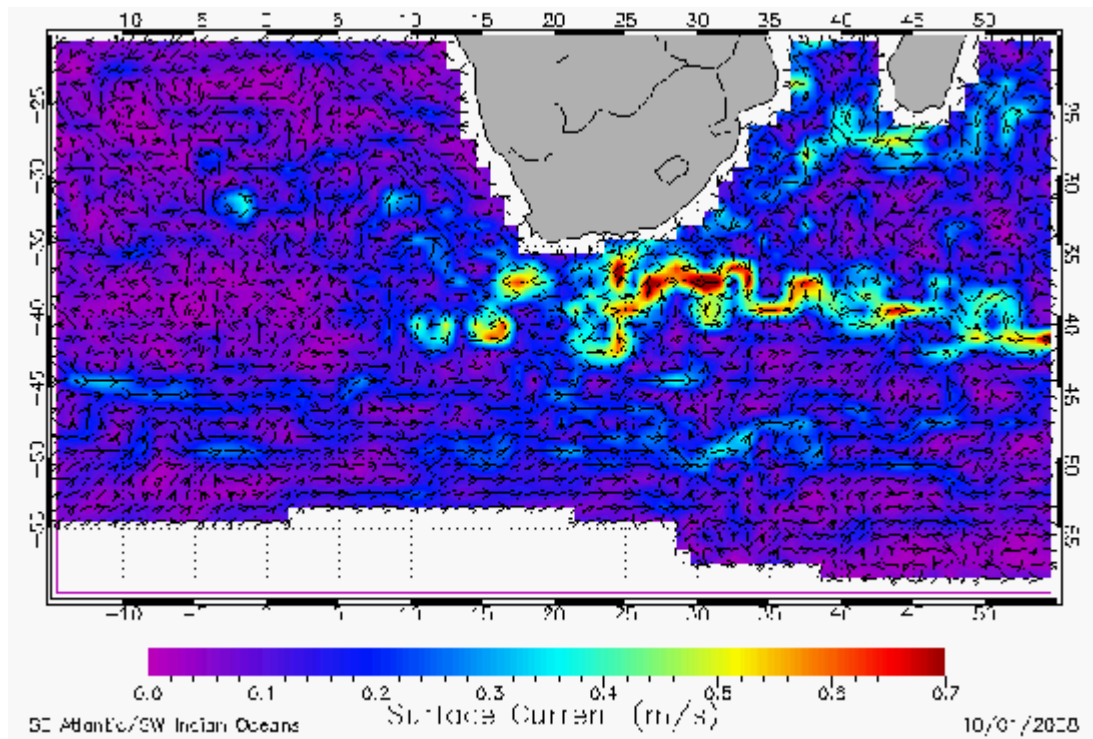


Figure A.17: Surface Currents around Southern Africa^[15]

The Antarctic Circumpolar Current, which runs in an easterly direction above Antarctica, is the largest wind-driven ocean current in the World^[14]. Figure A.18 provides an illustration^[16].

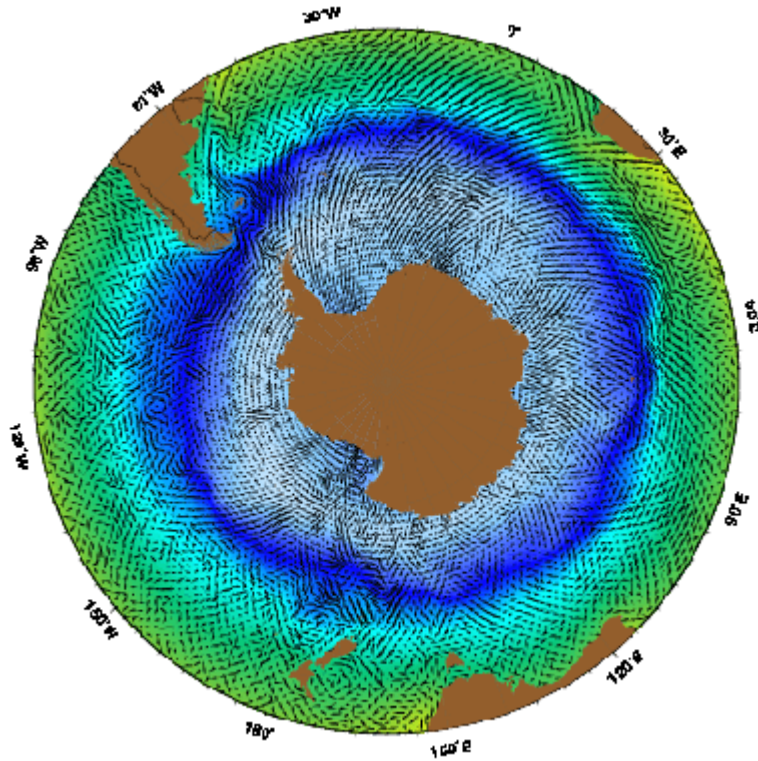


Figure A.18: Antarctic Circumpolar Current^[16]

The warm Agulhas Current runs south along the east coast, is fast and transports large volumes of water. Figure A.19 shows the path of the Agulhas Current^[17].

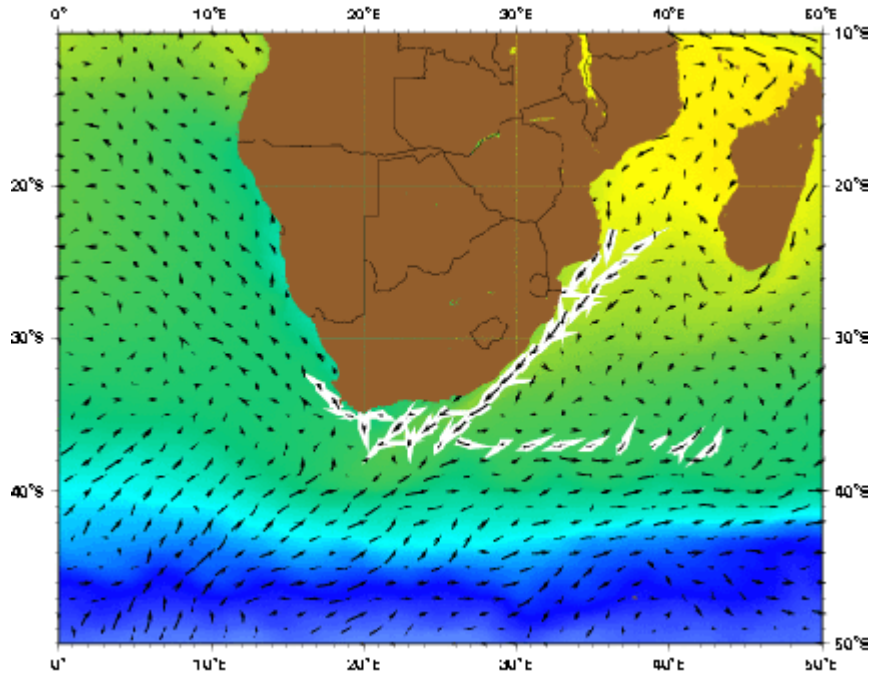


Figure A.19: Agulhas Current^[17]

The cold Benguela Current flows in a northerly direction along the west coast. Figure A.20 shows the path of the Benguela Current^[18].

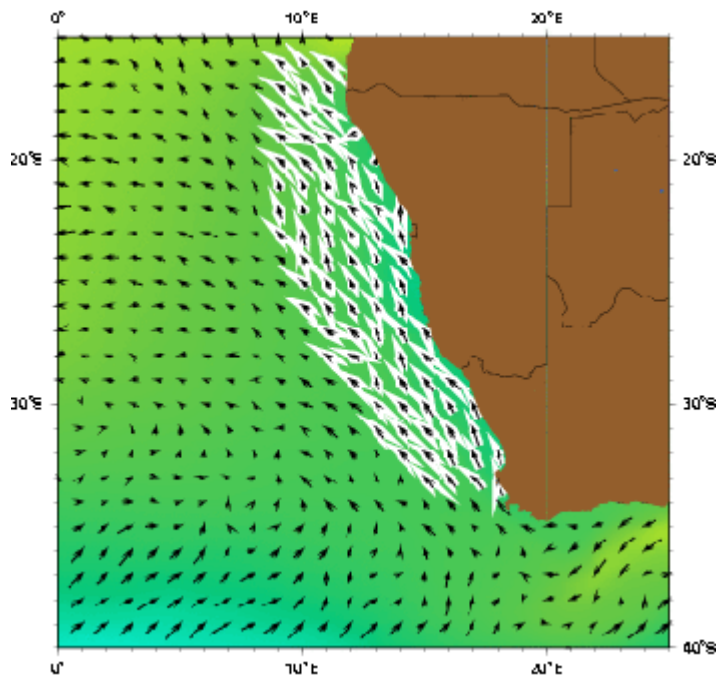


Figure A.20: Benguela Current^[18]

A.4 Tides

Figure A.21^[21] provides a graphical model of World oceanic tides and their amplitudes.

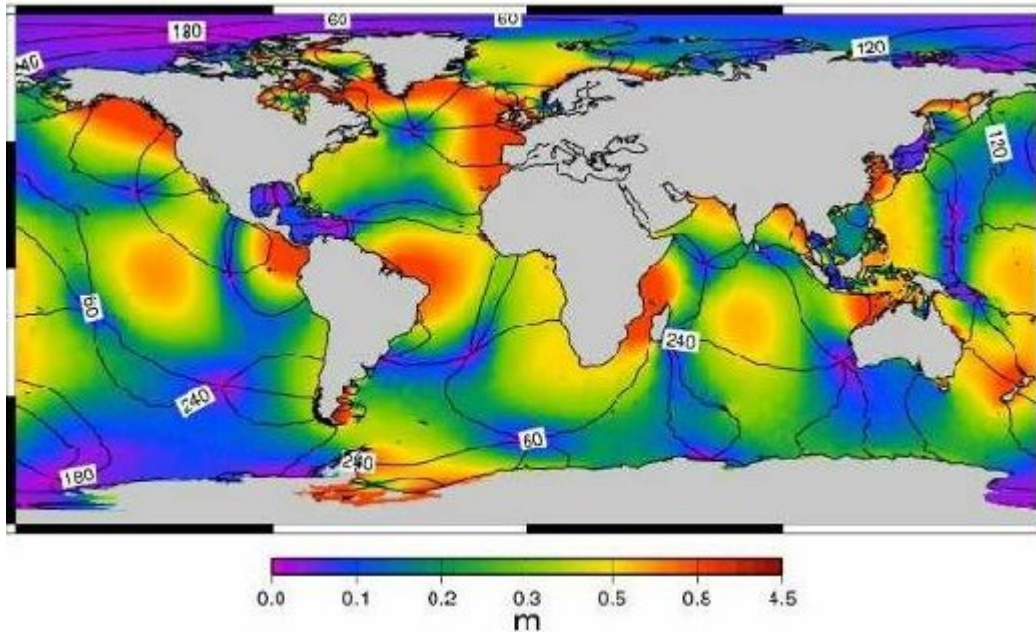


Figure A.21: Global Ocean Tides as Measured in 2006^[21]

A.5 Ocean Surface Temperatures

Figure A.22 depicts the mean sea surface temperatures globally.

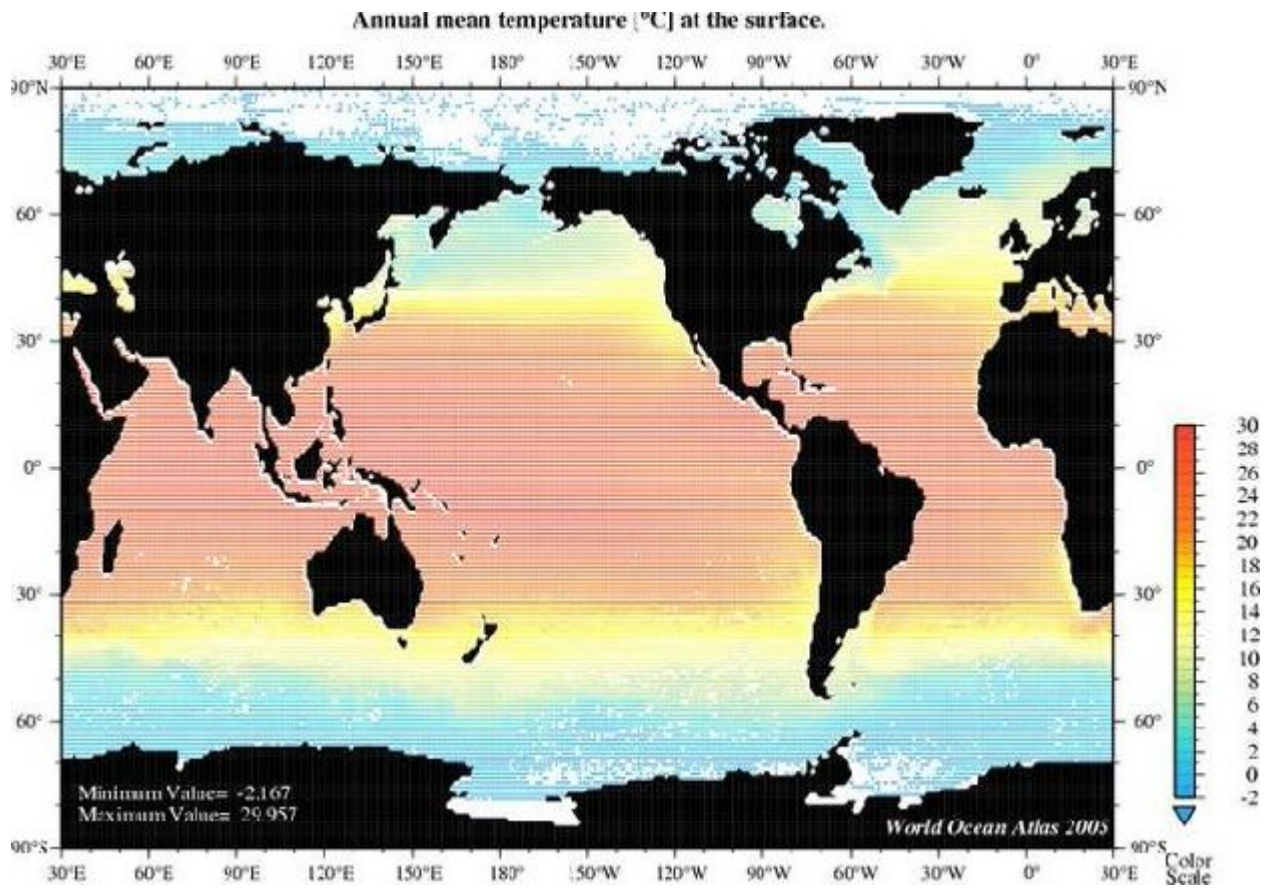


Figure A.22: Annual Mean Sea Surface Temperatures^[22]

Figure A.23 is a further depiction of sea surface temperatures, as measured over the time period 21 to 24 November 2009^[23]. From this chart it can be seen that surface temperatures range between 26°C and 16°C up to the around the Continental Shelf, but drop sharply beyond that to the minimum when moving towards the Antarctic coastline. Furthermore, it is apparent that the presence of ice is abundant, starting halfway between the South African coast and Antarctica. It should be noted that this is during Summer as well. Ice formation during Winter is more severe.

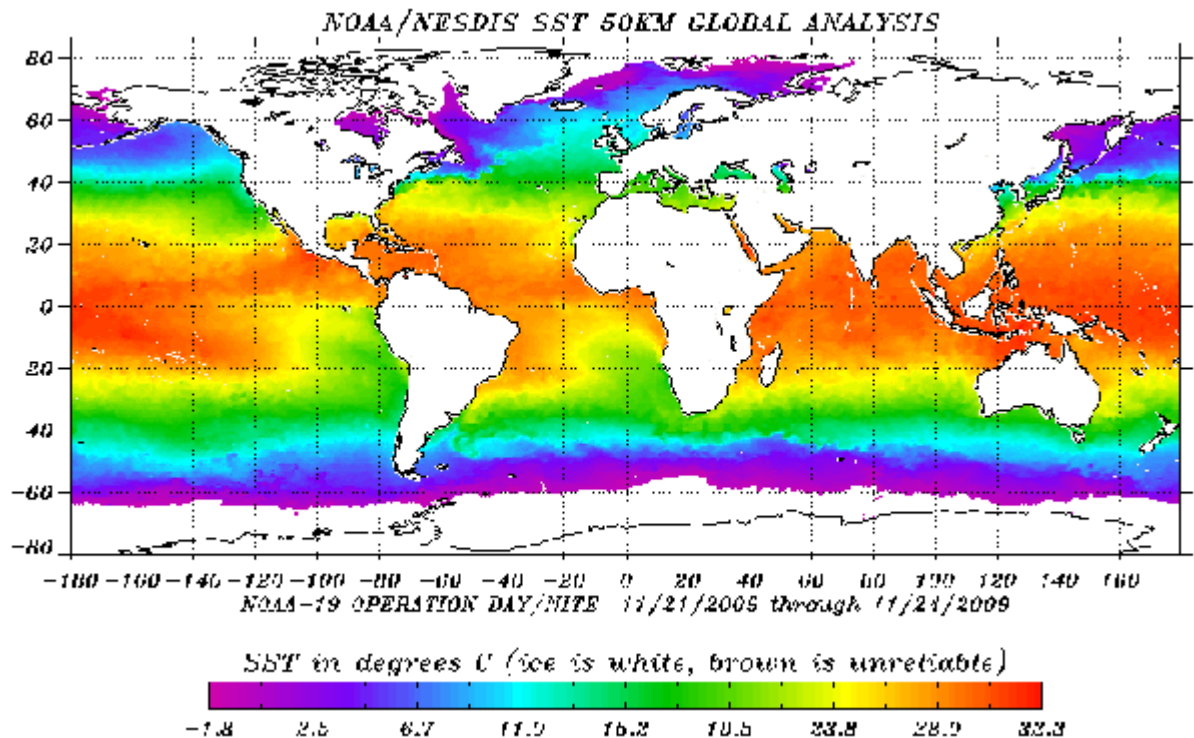


Figure A.23: Sea Surface Temperatures over Period 21 to 24 November 2009^[23]

Figure A.24 provides a close-up graph of the sea surface temperatures in the Southern Ocean, and around Southern Africa. The effect of the warmer Agulhas Current is clearly visible on the East and South Coast. The temperature ranges are similar to those for the previous two charts^[12].

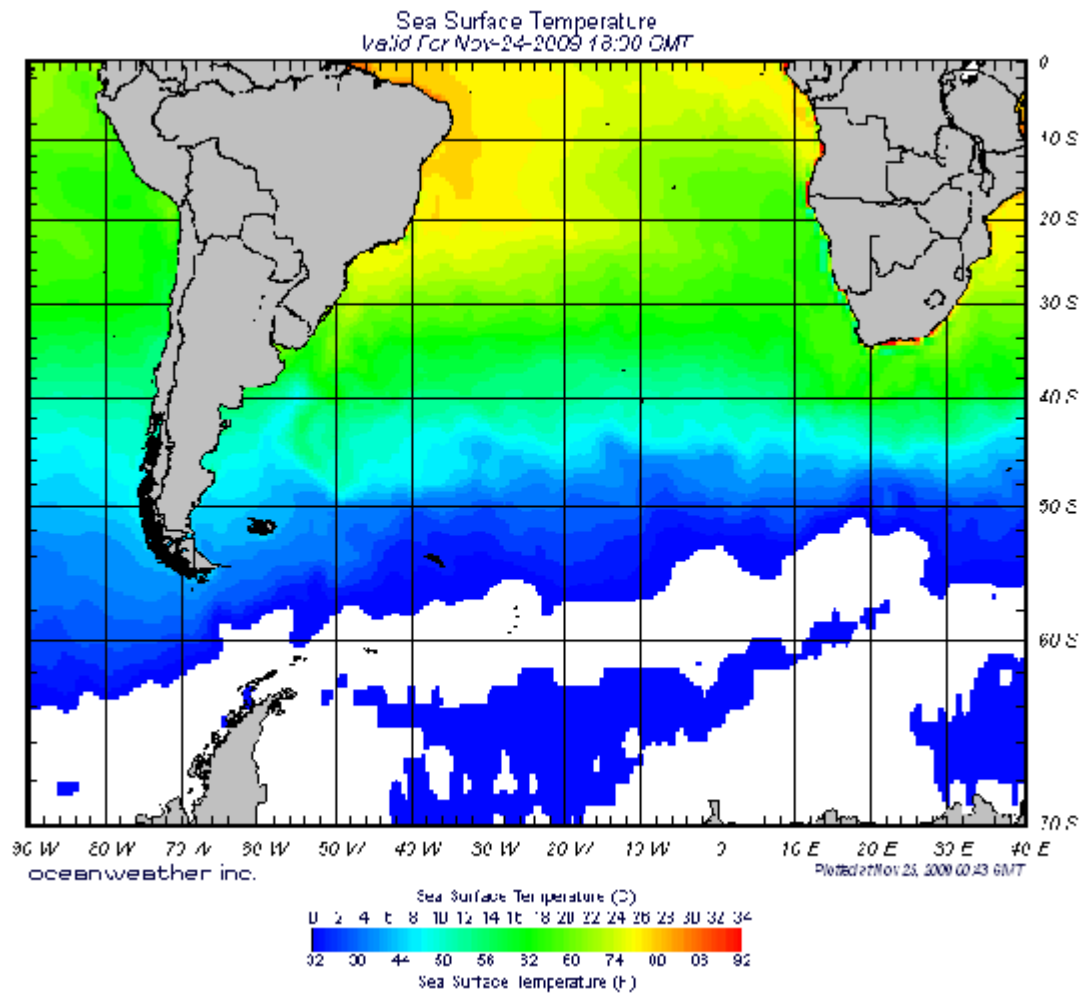


Figure A.24: Southern Sea Surface Temperatures as on 24 November 2009^[12]

A.6 Air Temperatures

Figure A.25 provides a graphical representation of the mean air temperature measured at sea level over the period January 2008 to October 2009^[24].

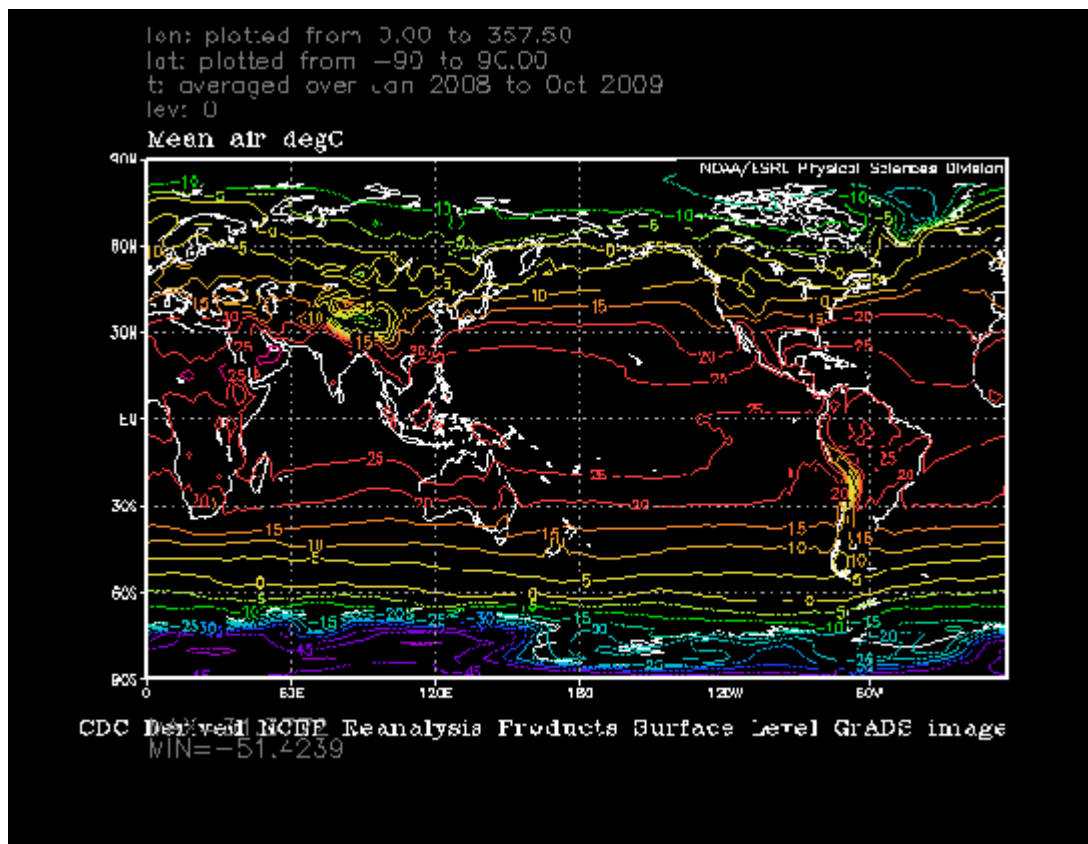


Figure A.25: Mean Air Temperature at Sea Level over Period January 2008 to October 2009^[24]

Figure A.26 provides a close-up of the Southern Ocean region.

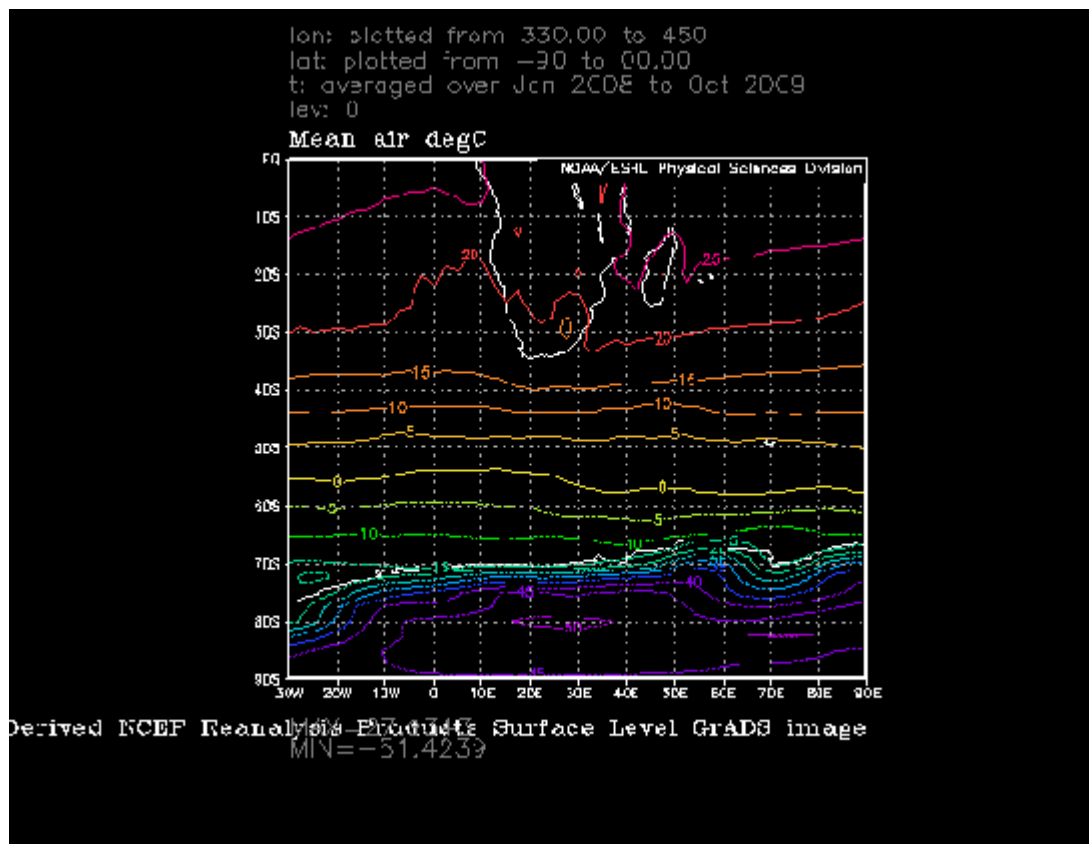


Figure A.26: Mean Air Temperature at Sea Level for Southern Ocean over Period January 2008 to October 2009^[24]

Appendix B

B. Fish Habitats

Appendix B analyses the natural habitats for some of the most important fish species found in and around the coasts of Southern Africa. Commercial, recreational and sustenance fishing requires hardware and personnel resources (i.e, boats and people to man them) to accomplish the task. A thorough knowledge of the natural habitats of fish species caught for commercial and recreational use will indicate the most probable areas where manned vessels will operate. This, in turn, will provide a picture of the focal area where Search and Rescue services will be required to operate most efficiently, as far as Fisheries is concerned.

The analysis looks at a sampling of some of the most popular fish species targeted by commercial, recreational and sustenance fisheries in South Africa. Approximately 150 species of fish species are targeted by line fishers in South Africa, and only a small sample is analysed here. Although the list is by far not exhaustive, it does provide a good indication of where most of the fishing takes place around our coasts, i.e. where many of the boats and ships operate on a daily basis.

The source for most of the information used in this analysis is FishBase^[50]. FishBase contains habitat and other information for 31400 species of fish. SeaLifeBase was also used to determine the habitat for certain crustaceans fished around our shores. This information was bolstered by information found at other sources, as indicated.

From the analysis it is obvious that most of the fish and crustacean species targeted around our coasts live within the 350nmi Continental Shelf zone. By far the greater portion lives very close to the shores, probably within the 24nmi Contiguous Zone. Most fishing takes place within the Continental Shelf zone, as the country has automatic rights to resources found within this area. The only species (of those analysed) found beyond the Continental Shelf zone are the tunas, mackerels, elf (shad), dorado and the Patagonian toothfish. Of those, only the Patagonian toothfish is not found closer to shore; its habitat

starts at some point beyond the Continental Shelf zone of the continent. However, this species is also found around the Prince Edward/Marion Islands.

Barring the fact that most fish species can be (and are) targeted within the Exclusive Economic Zone, fishing does take place up to the extremities of the national Search and Rescue Region. It therefore goes without saying that Search and Rescue resources need to be capable of reaching these extremities within reasonable time be able to respond to distressed fishing vessels operating at those locations.

The graphs below provide a graphical presentation of the native habitats for the species analysed^[50]. The colours provide the relative probabilities of occurrence as follows.

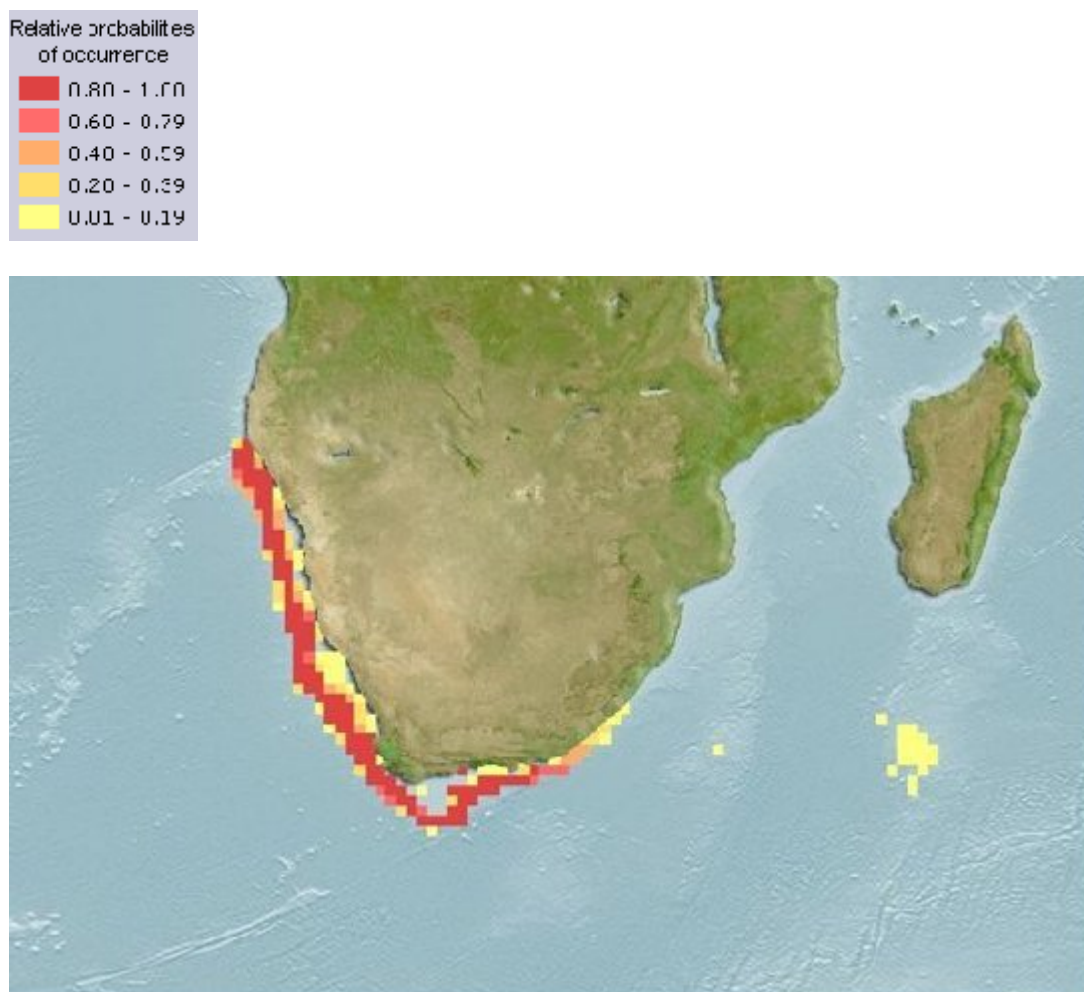


Figure B.1: Natural Habitat of Deepwater Hake



Figure B.2: Natural Habitat of Shallow-water Cape Hake

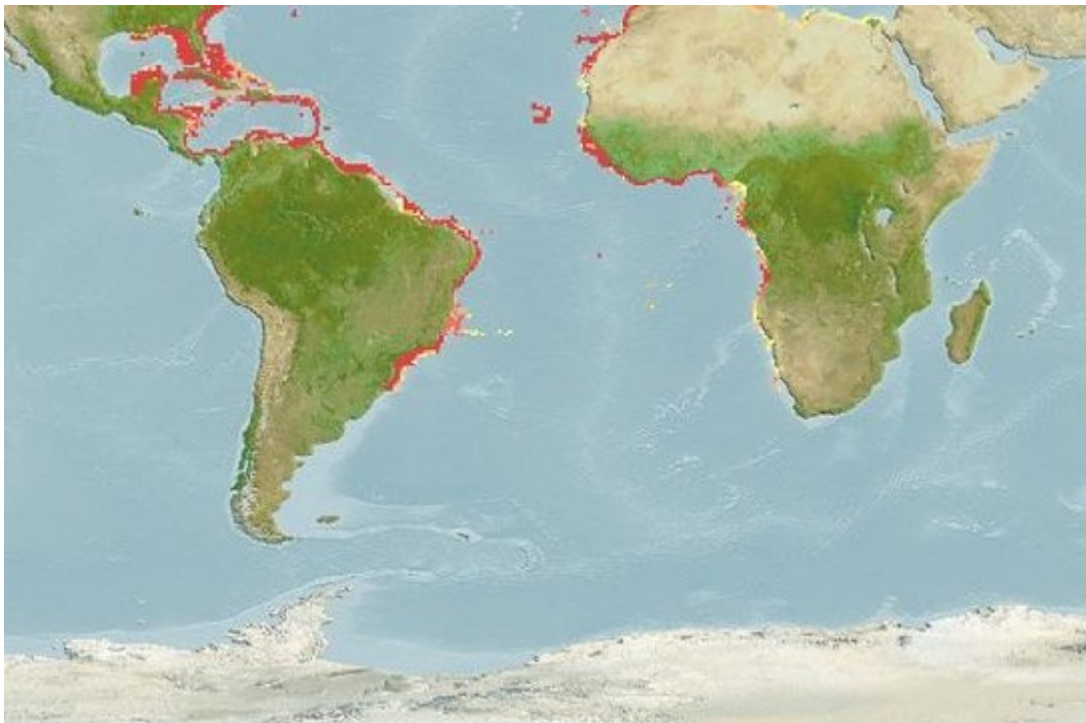


Figure B.3: Natural Habitat of Atlantic Little Tuna

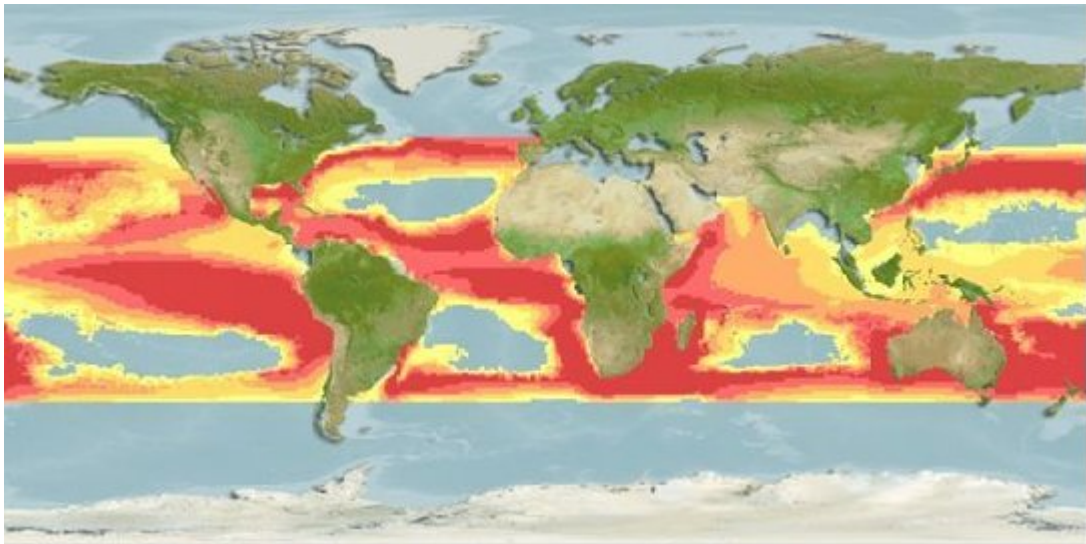


Figure B.4: Natural Habitat of Bigeye Tuna

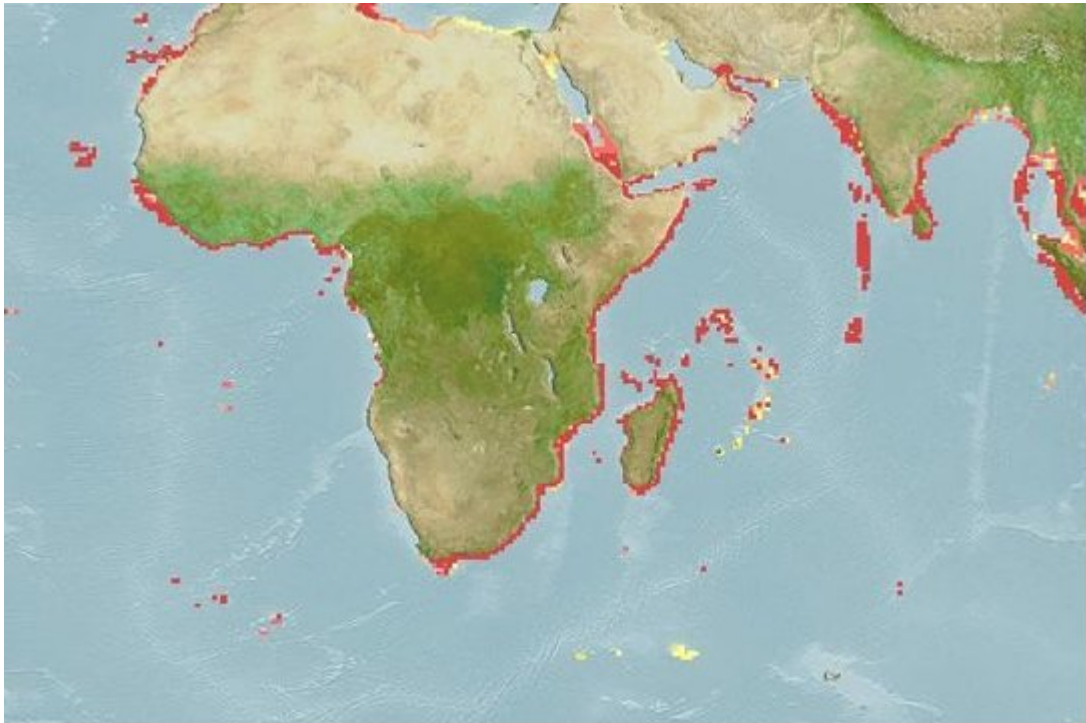


Figure B.5: Natural Habitat of Bullet Tuna

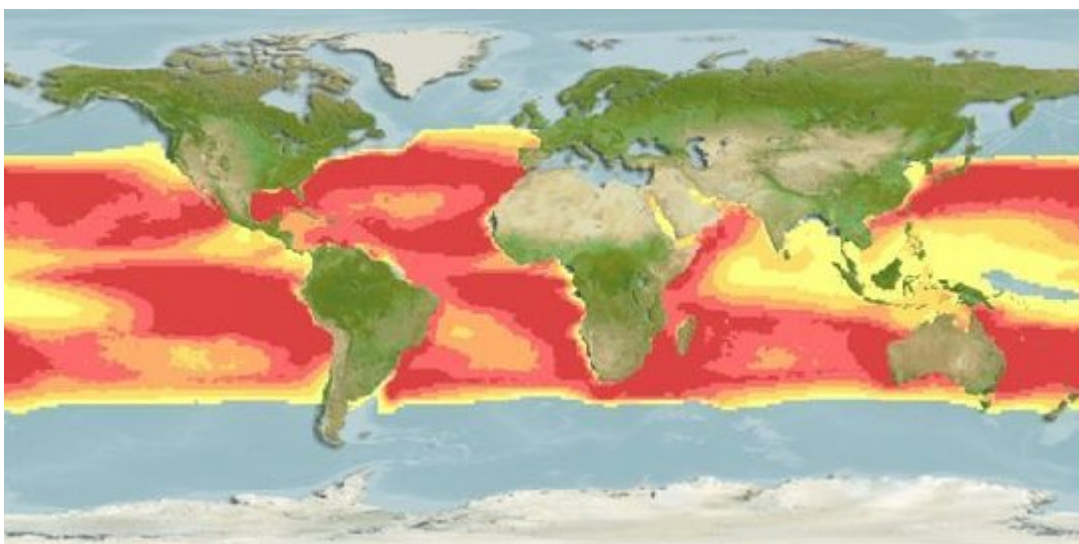


Figure B.6: Natural Habitat of Yellowfin Tuna

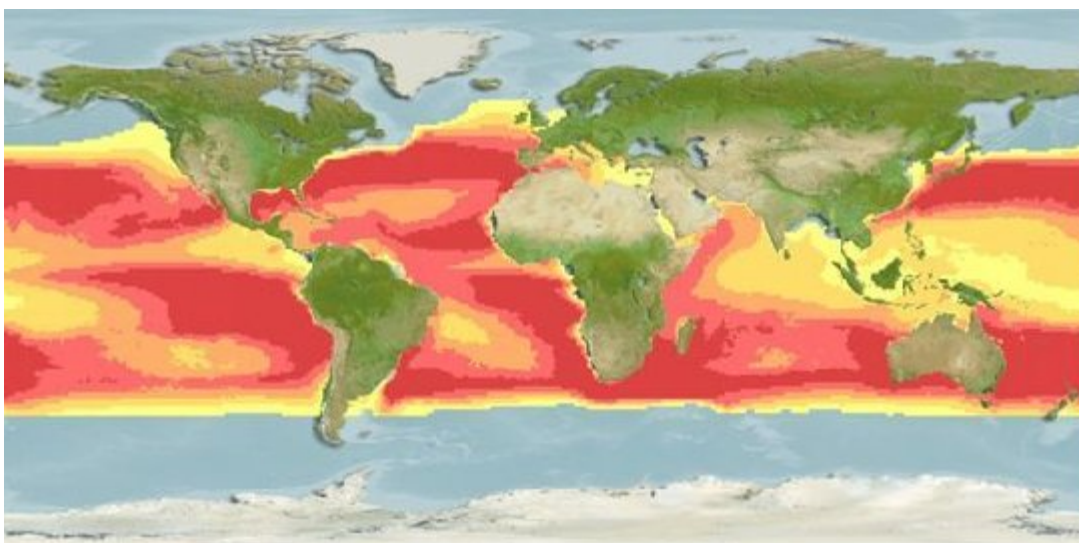


Figure B.7: Natural Habitat of Longfin Tuna

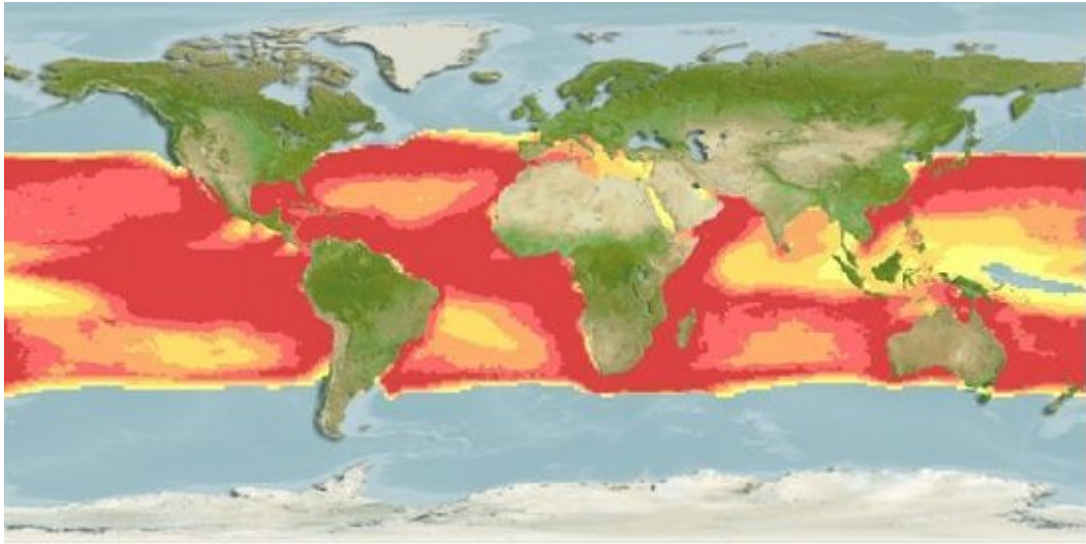


Figure B.8: Natural Habitat of Skipjack Tuna

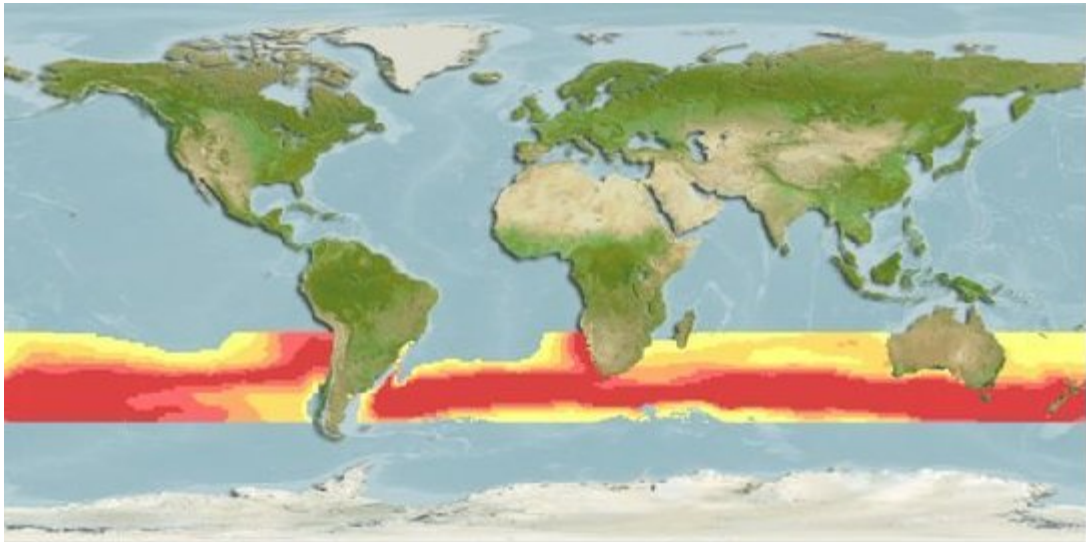


Figure B.9: Natural Habitat of Slender Tuna

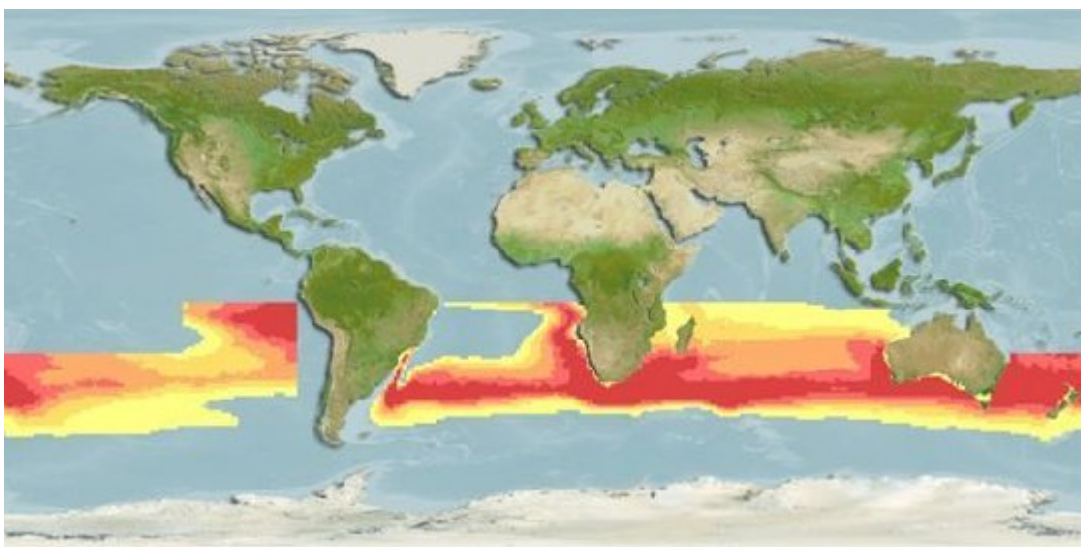


Figure B.10: Natural Habitat of Southern Bluefin Tuna

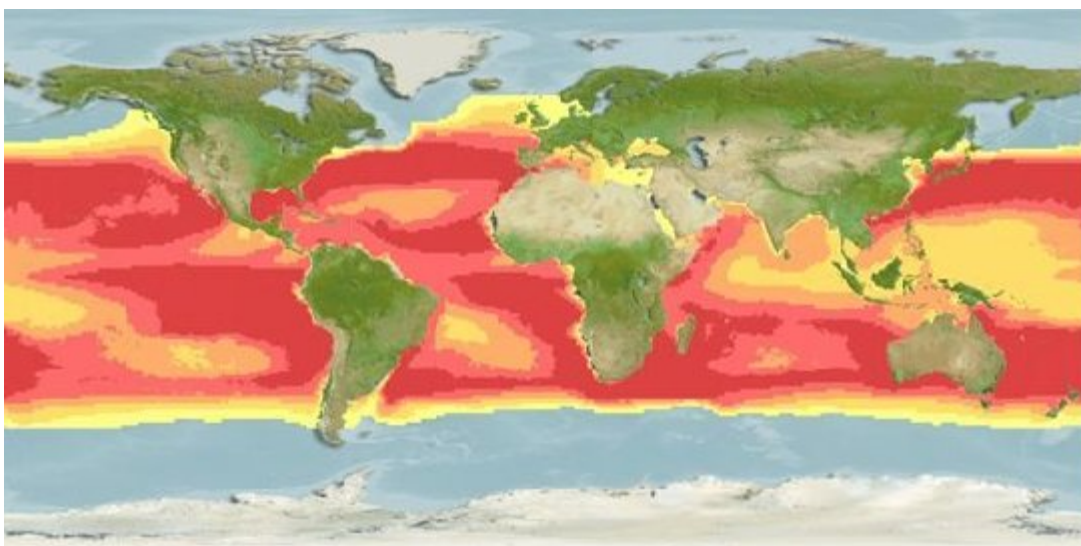


Figure B.11: Natural Habitat of Swordfish

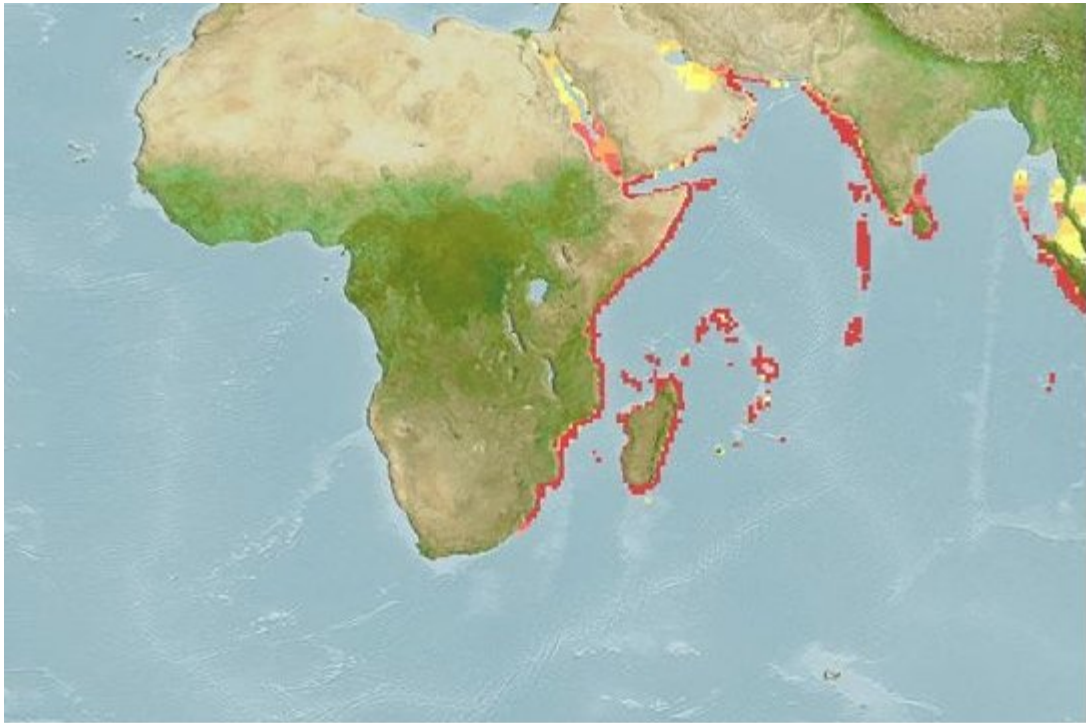


Figure B.12: Natural Habitat of Buccaneer Anchovy

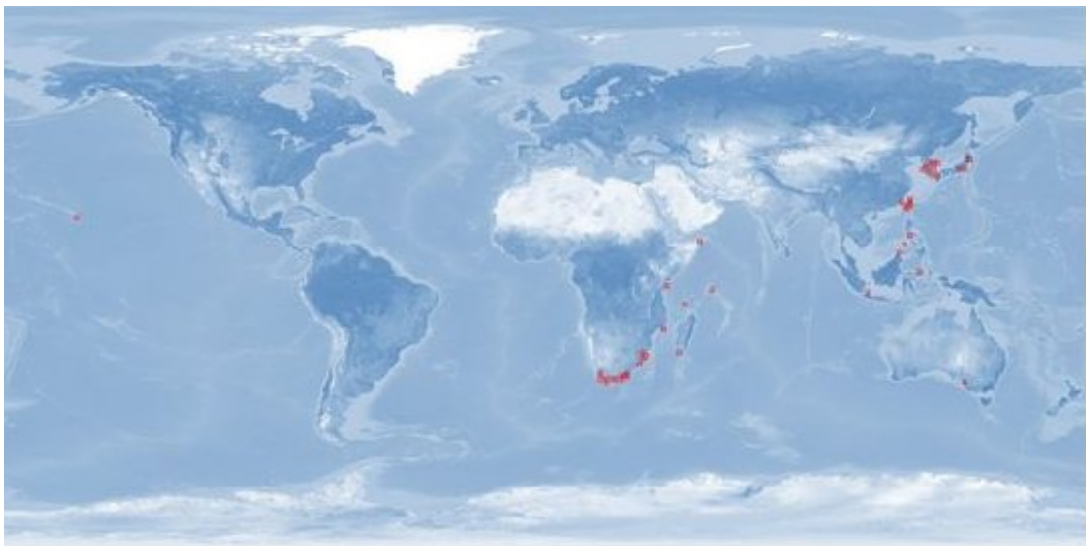


Figure B.13: Natural Habitat of Cape Anchovy

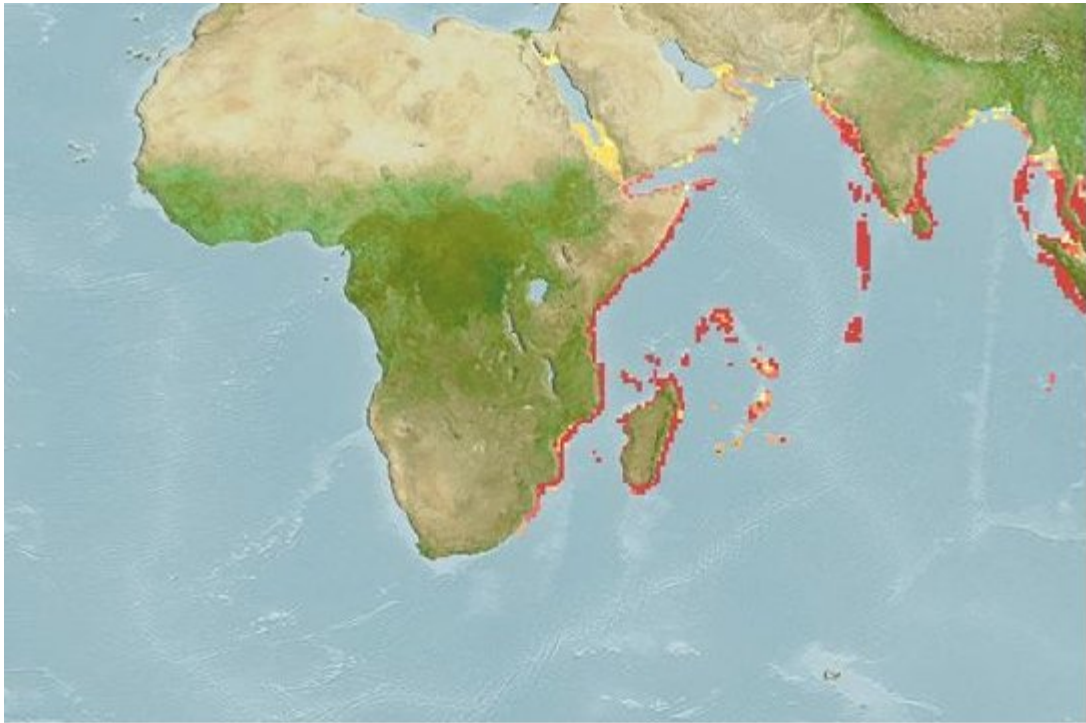


Figure B.14: Natural Habitat of Indian Anchovy



Figure B.15: Natural Habitat of Thorny Anchovy



Figure B.16: Natural Habitat of European Anchovy



Figure B.17: Natural Habitat of South American Pilchard



Figure B.18: Natural Habitat of Round Sardinelle

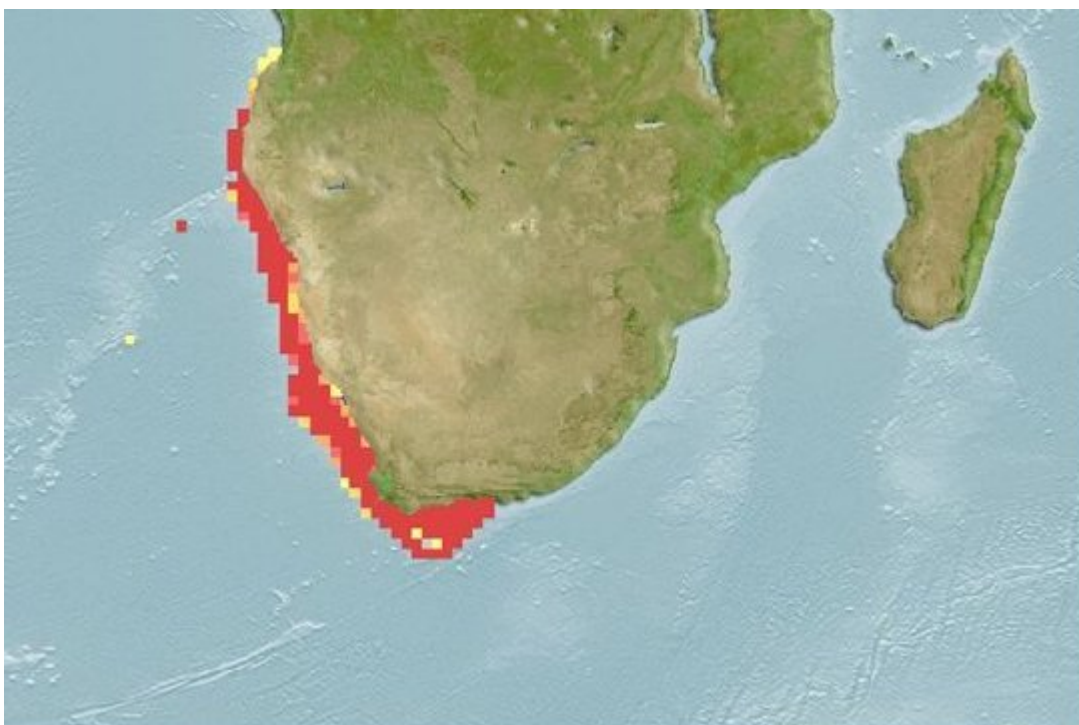


Figure B.19: Natural Habitat of Cape Horse Mackerel

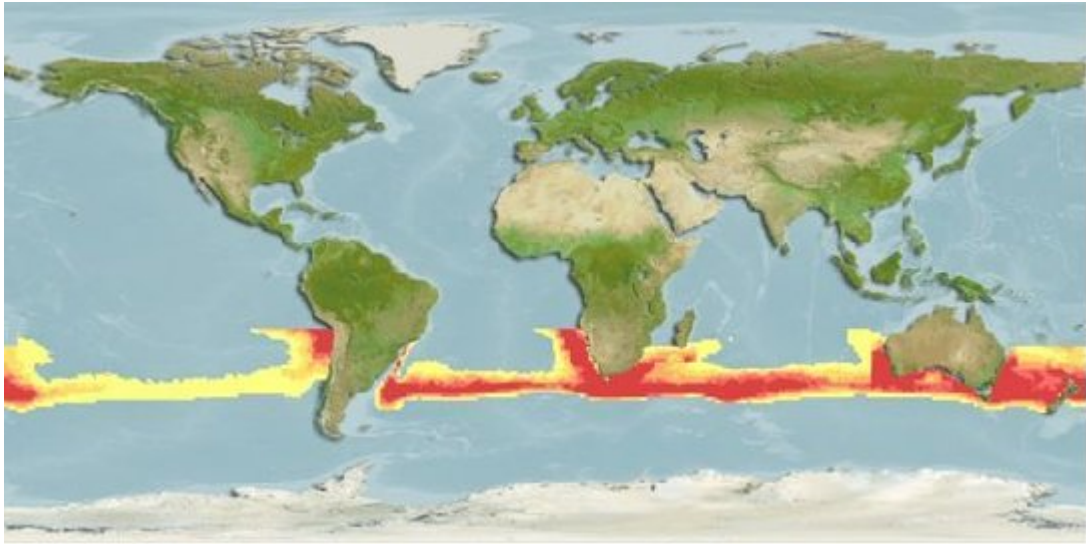


Figure B.20: Natural Habitat of Bigscale Mackerel

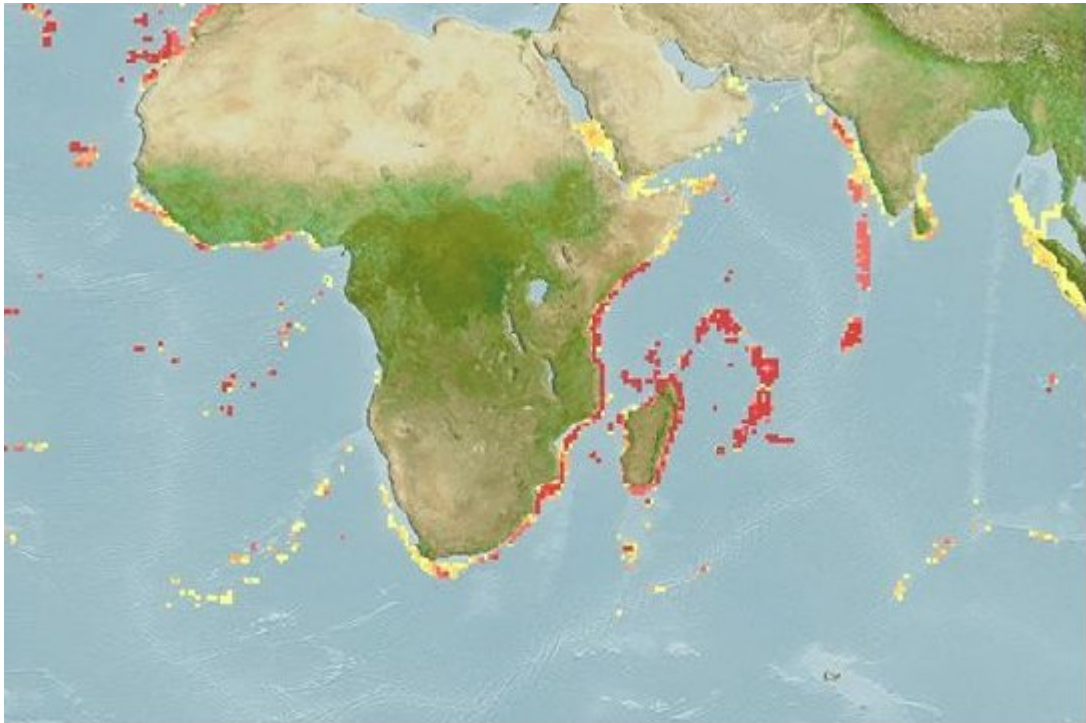


Figure B.21: Natural Habitat of Black Mackerel

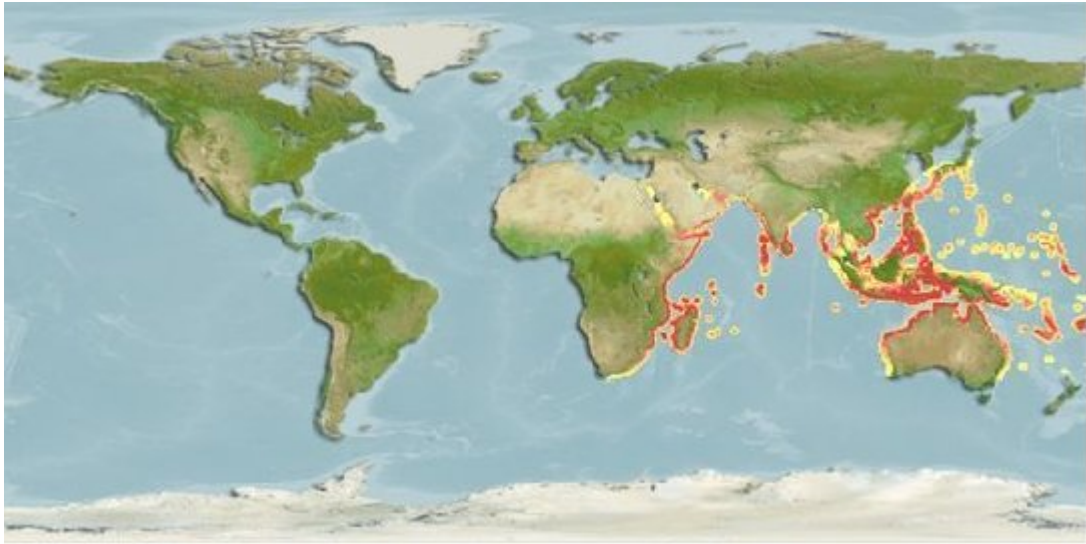


Figure B.22: Natural Habitat of Indian Mackerel

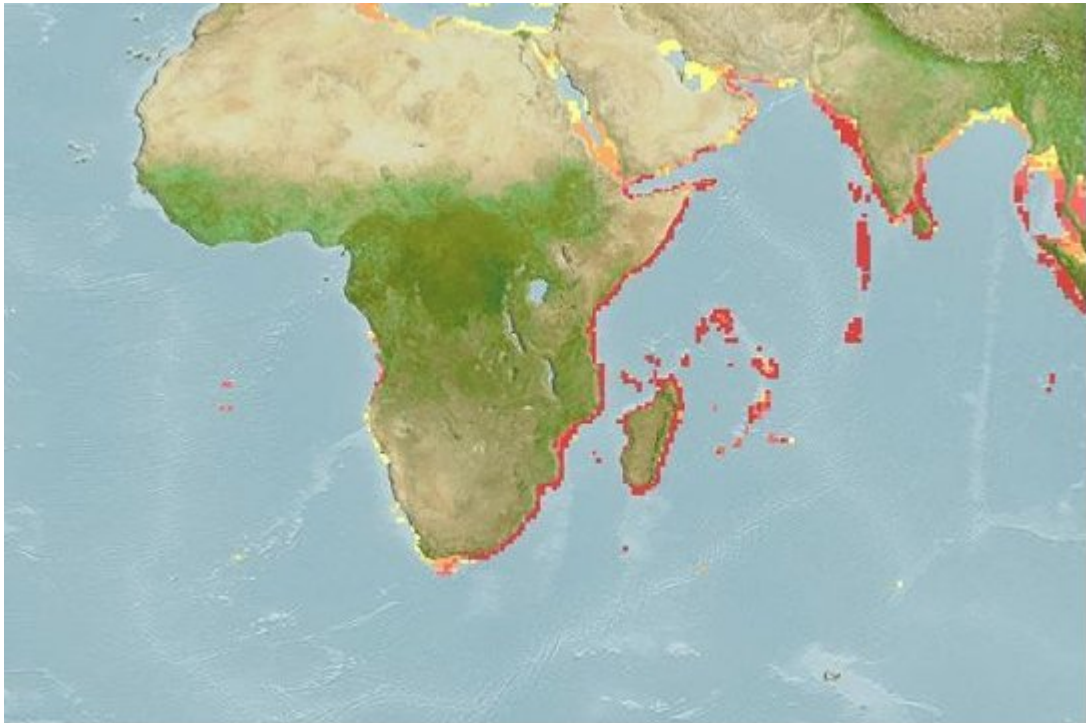


Figure B.23: Natural Habitat of King Mackerel

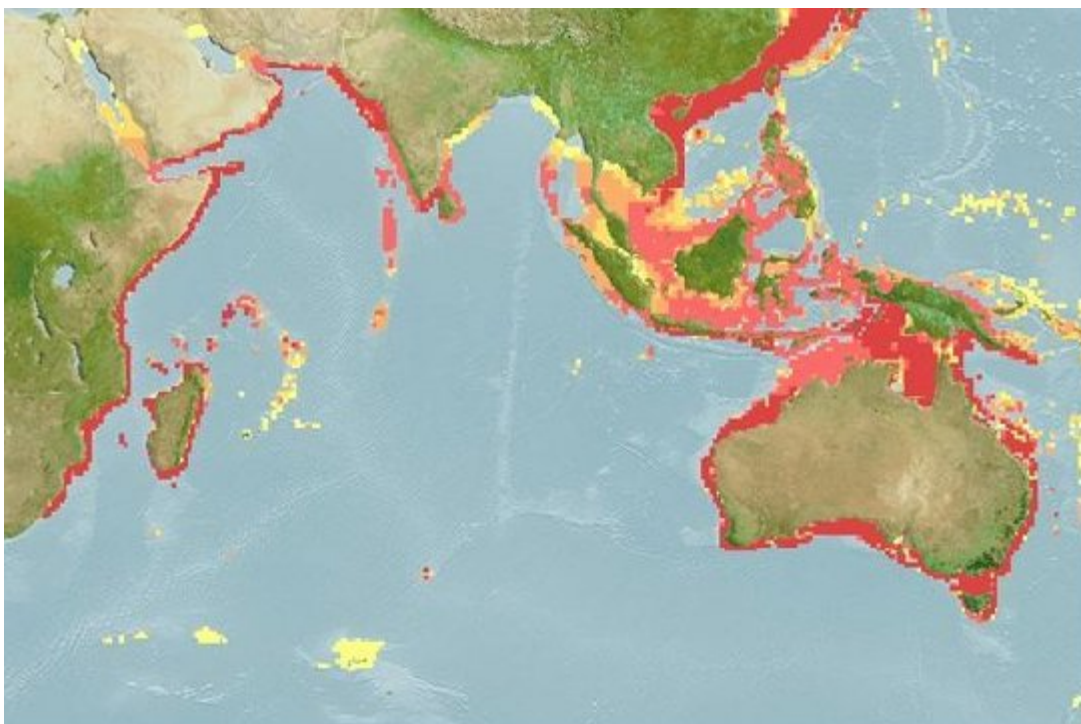


Figure B.24: Natural Habitat of Chub Mackerel

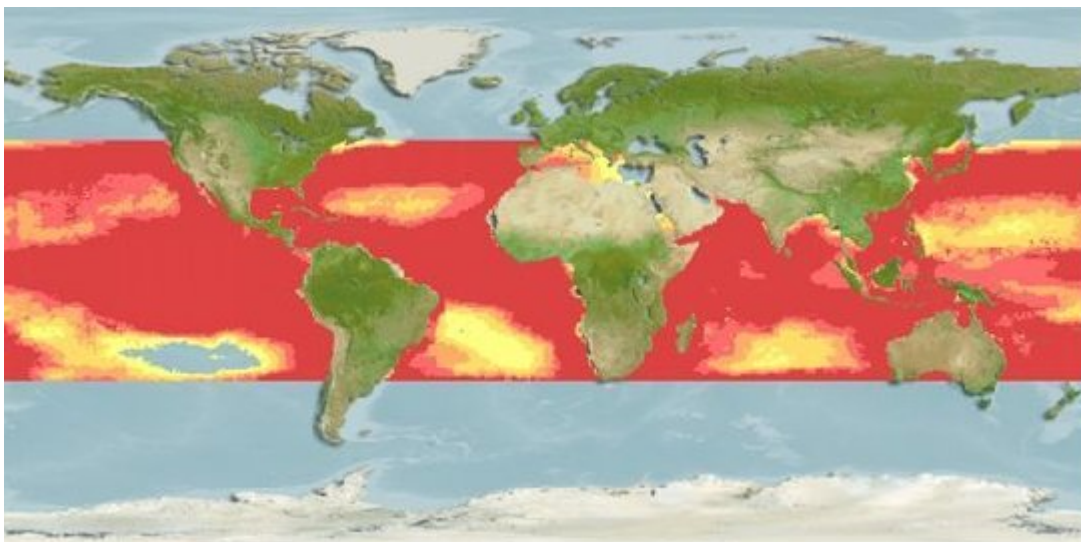


Figure B.25: Natural Habitat of Mackerel Scad

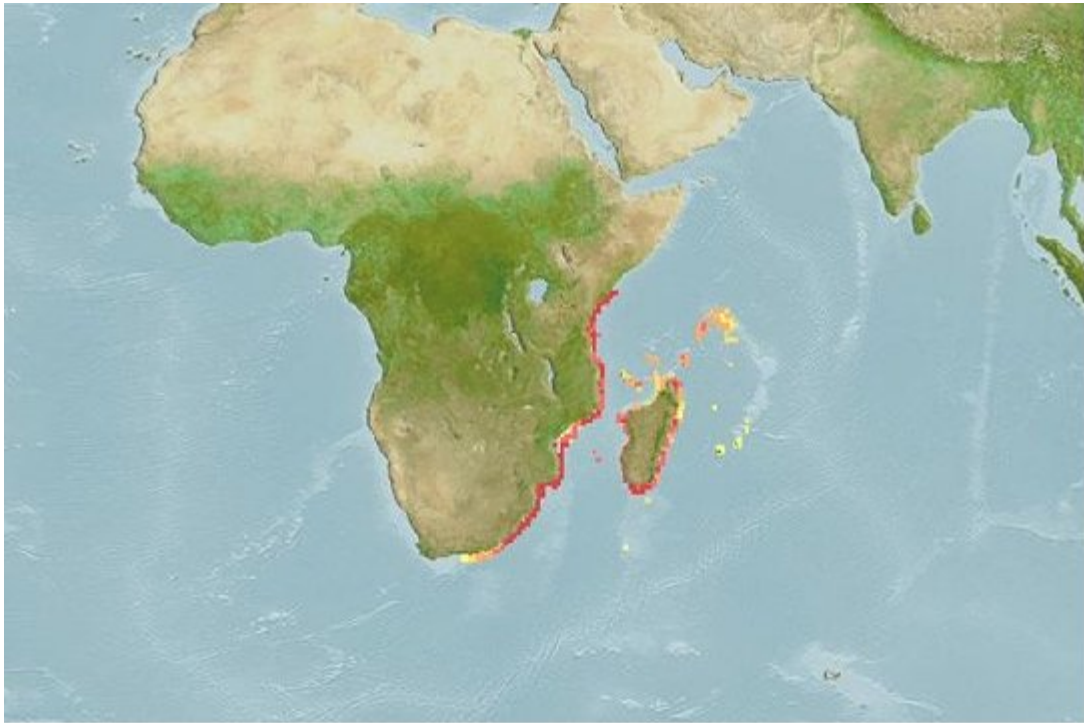


Figure B.26: Natural Habitat of Spotted Mackerel/Natal Snoek

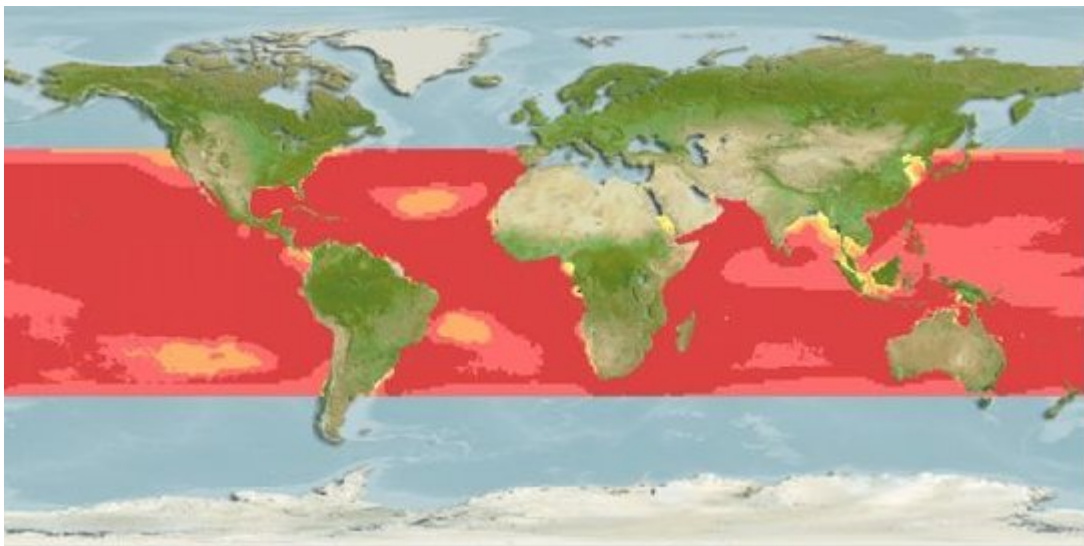


Figure B.27: Natural Habitat of Snake Mackerel

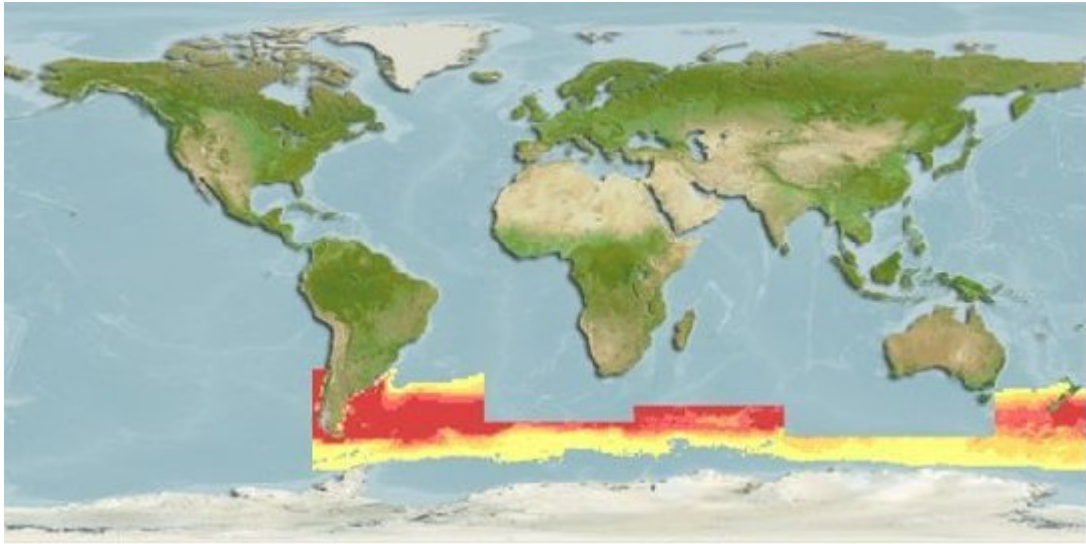


Figure B.28: Natural Habitat of Patagonian Toothfish

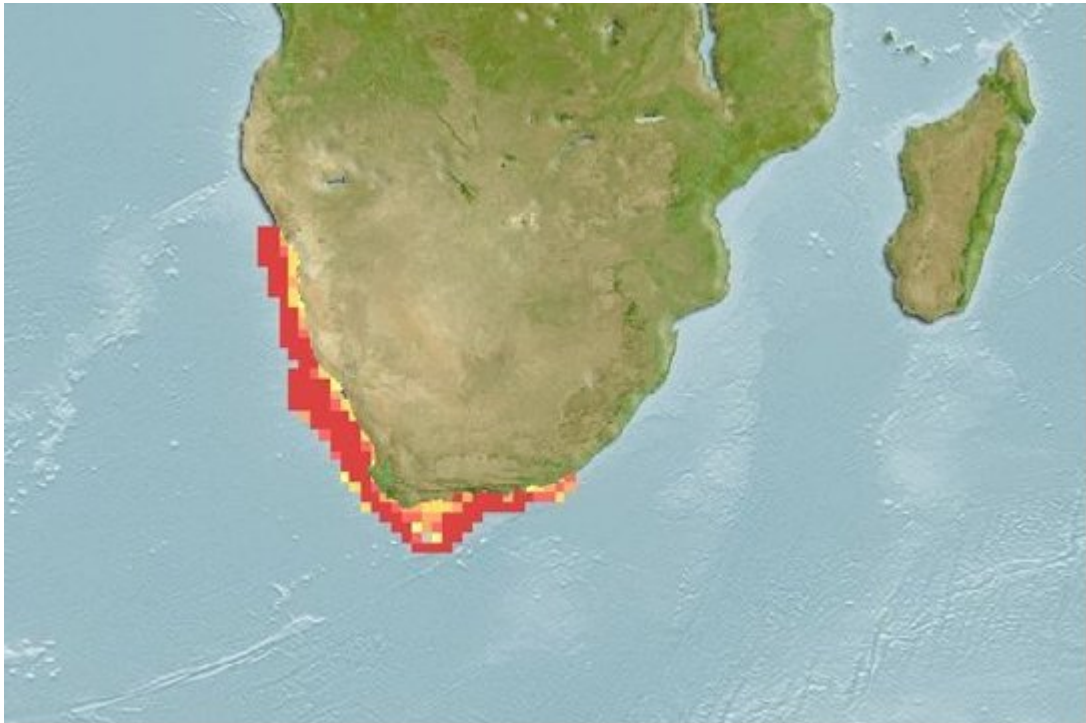


Figure B.29: Natural Habitat of Cape Kingklip



Figure B.30: Natural Habitat of Blackhand Sole



Figure B.31: Natural Habitat of Cape Sole

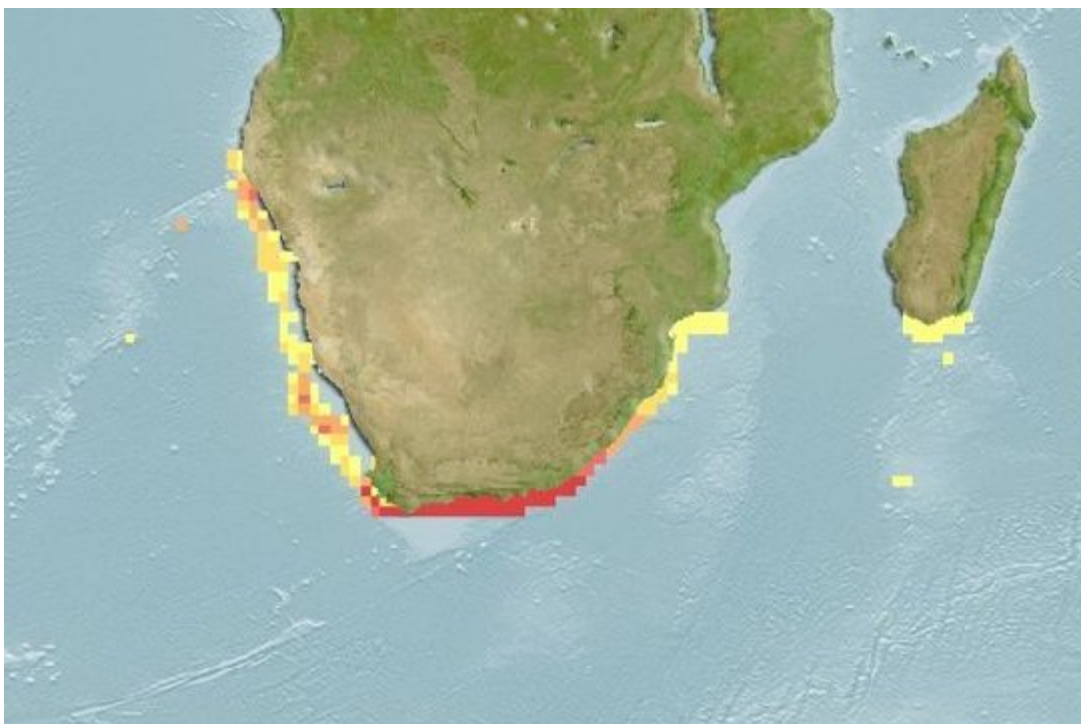


Figure B.32: Natural Habitat of East Coast Solepo

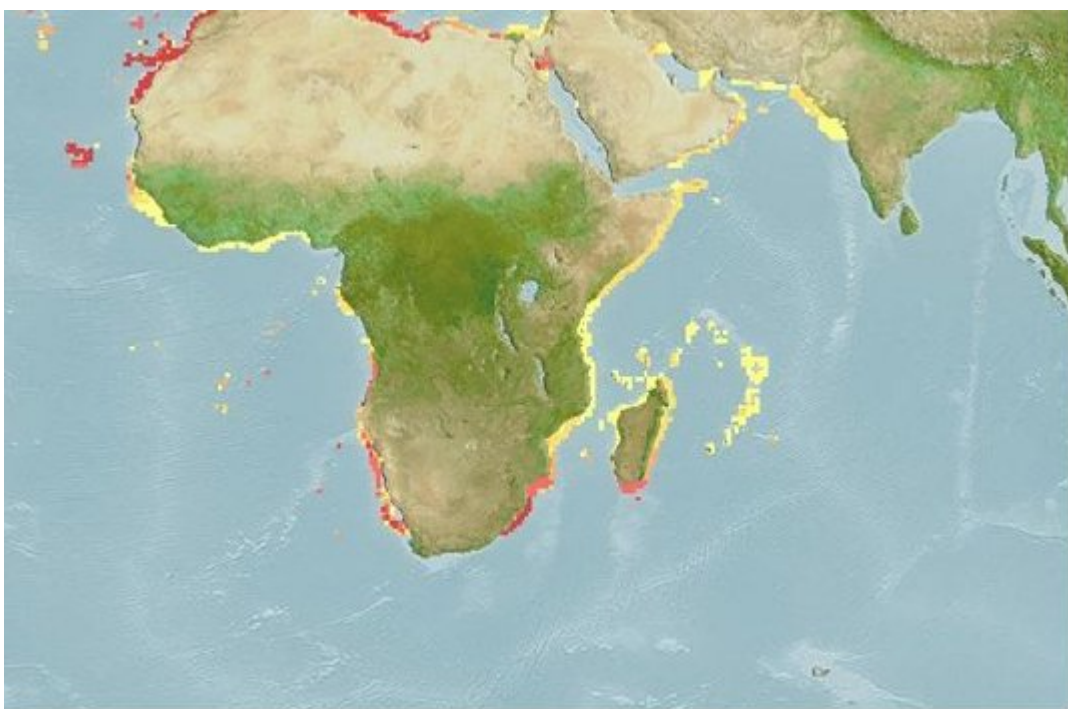


Figure B.33: Natural Habitat of Lace Sole

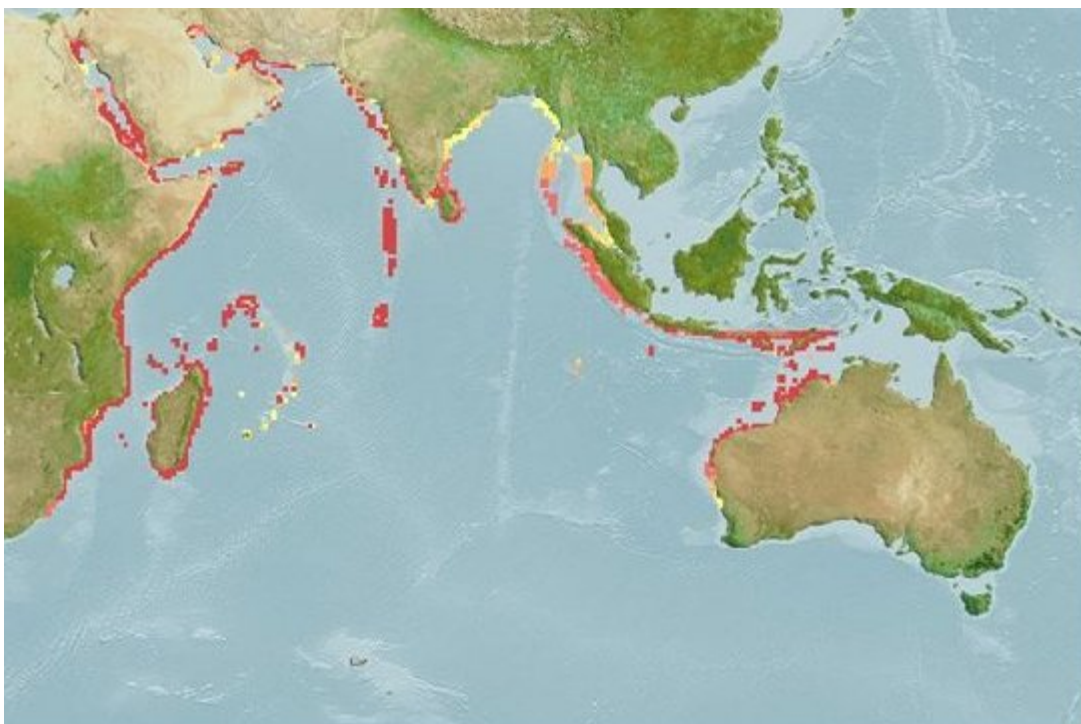


Figure B.34: Natural Habitat of Speckled Sole

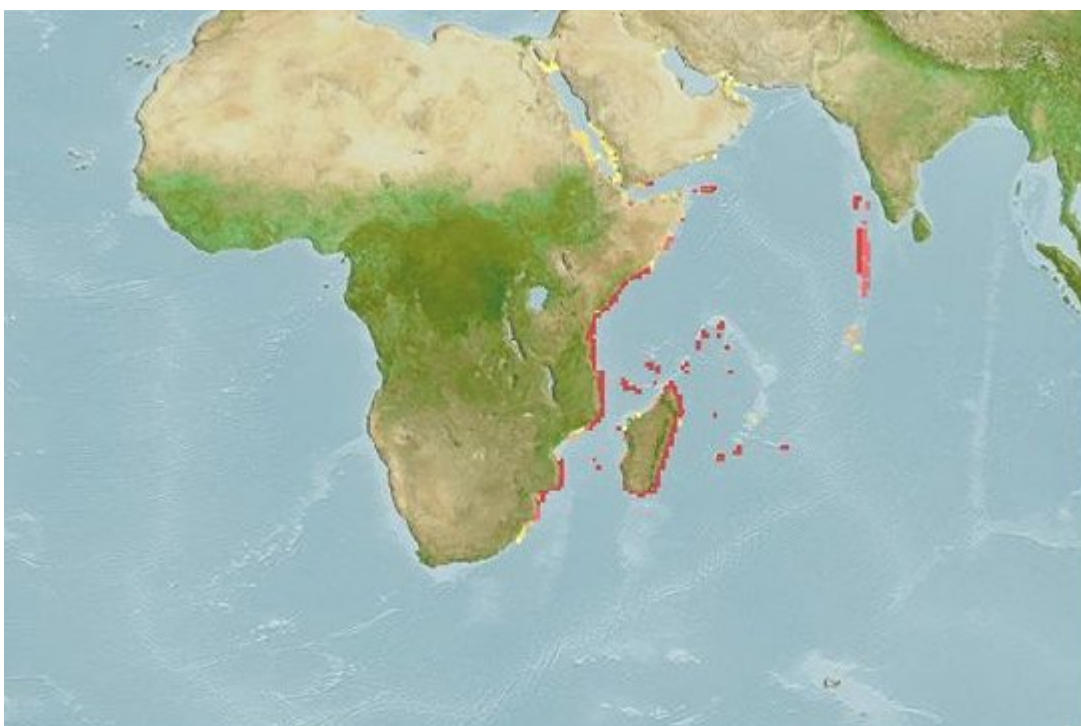


Figure B.35: Natural Habitat of Twoline Tonguesole



Figure B.36: Natural Habitat of Wedge Sole

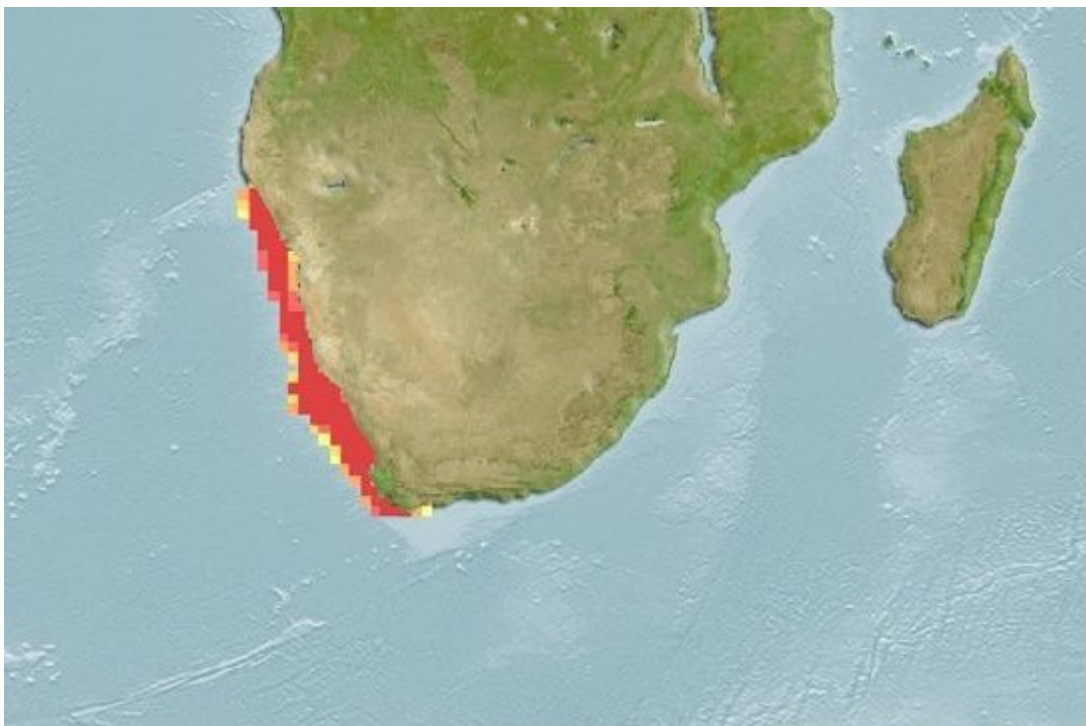


Figure B.37: Natural Habitat of West Coast Sole

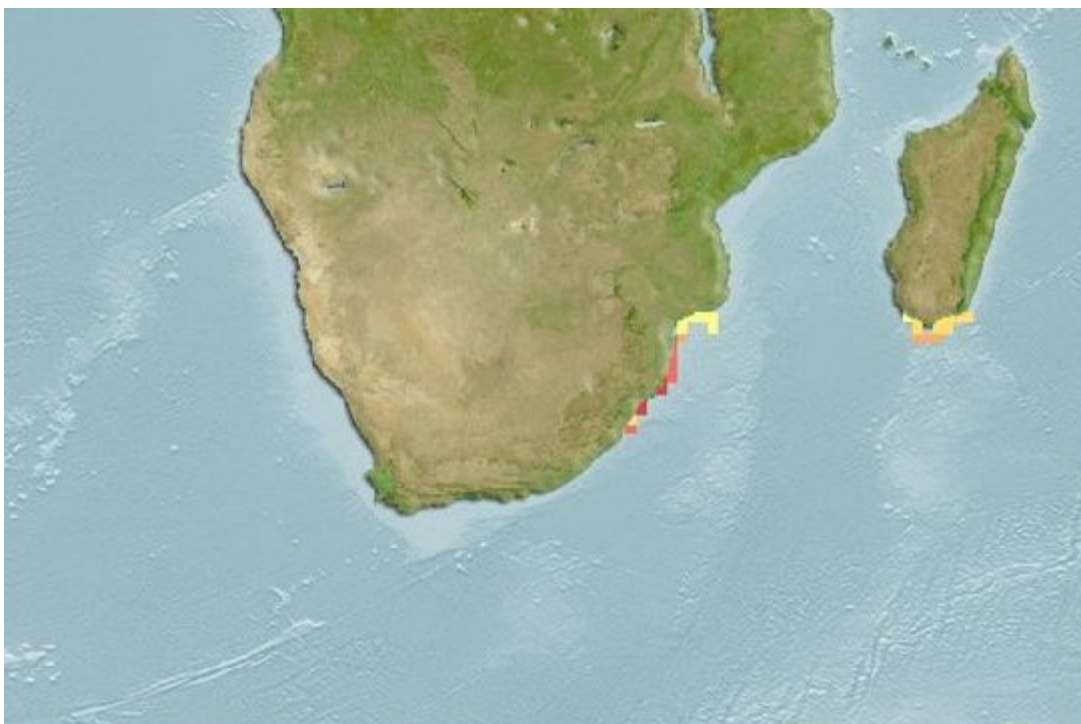


Figure B.38: Natural Habitat of Zebra Sole

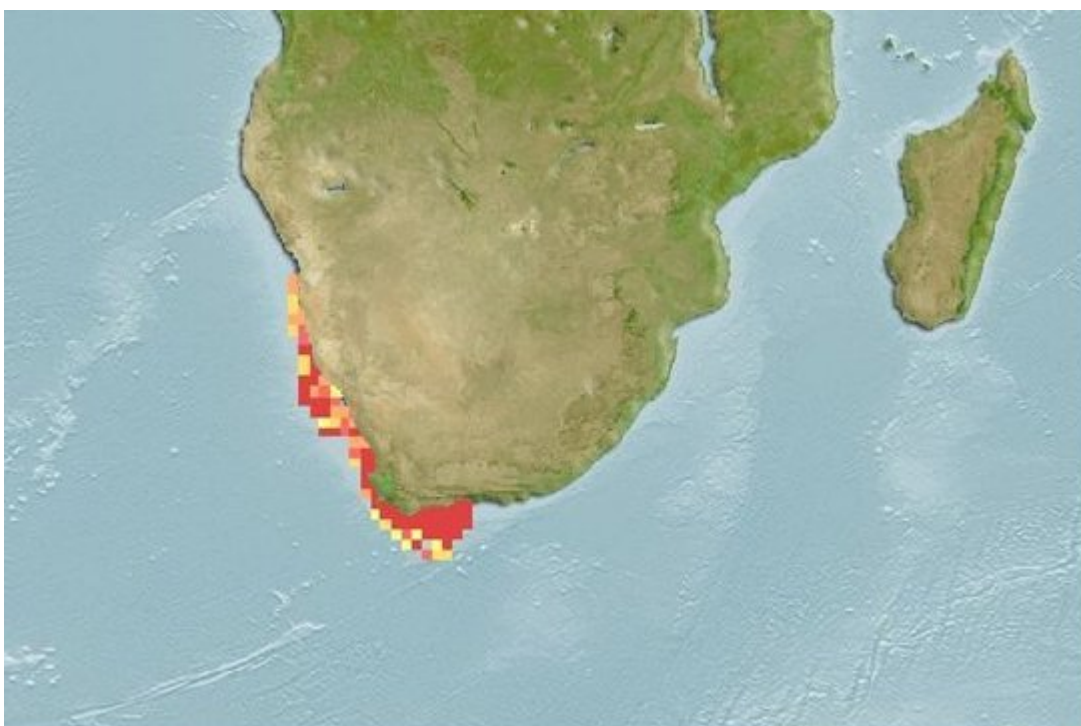


Figure B.39: Natural Habitat of Redeye Herring

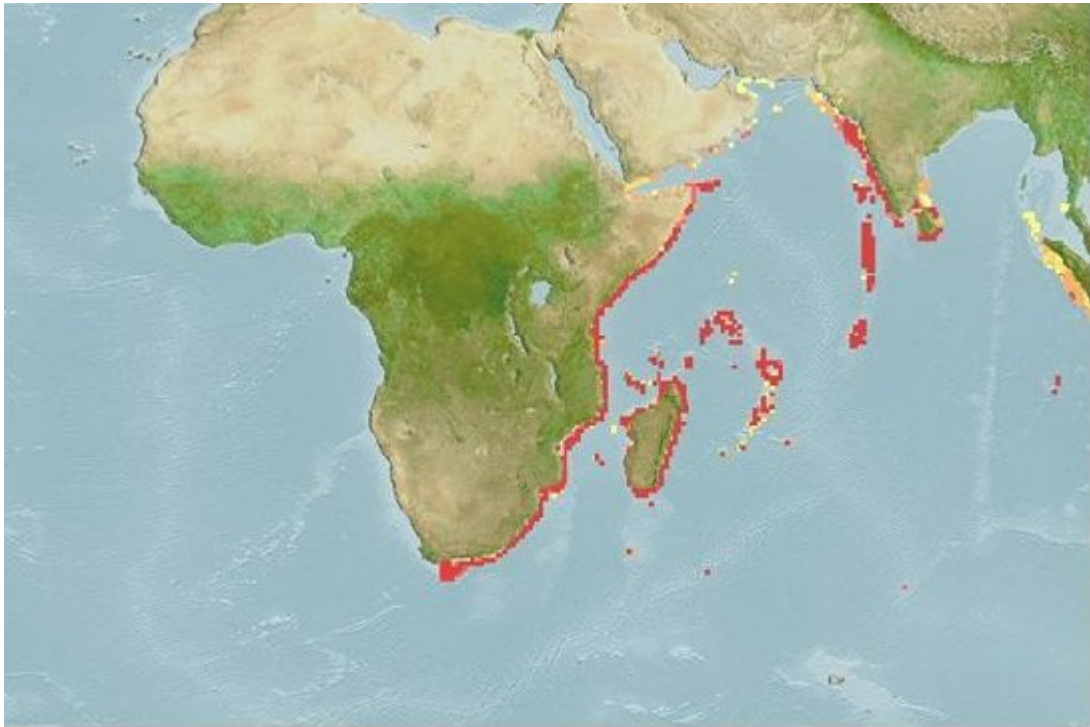


Figure B.40: Natural Habitat of Black Snook

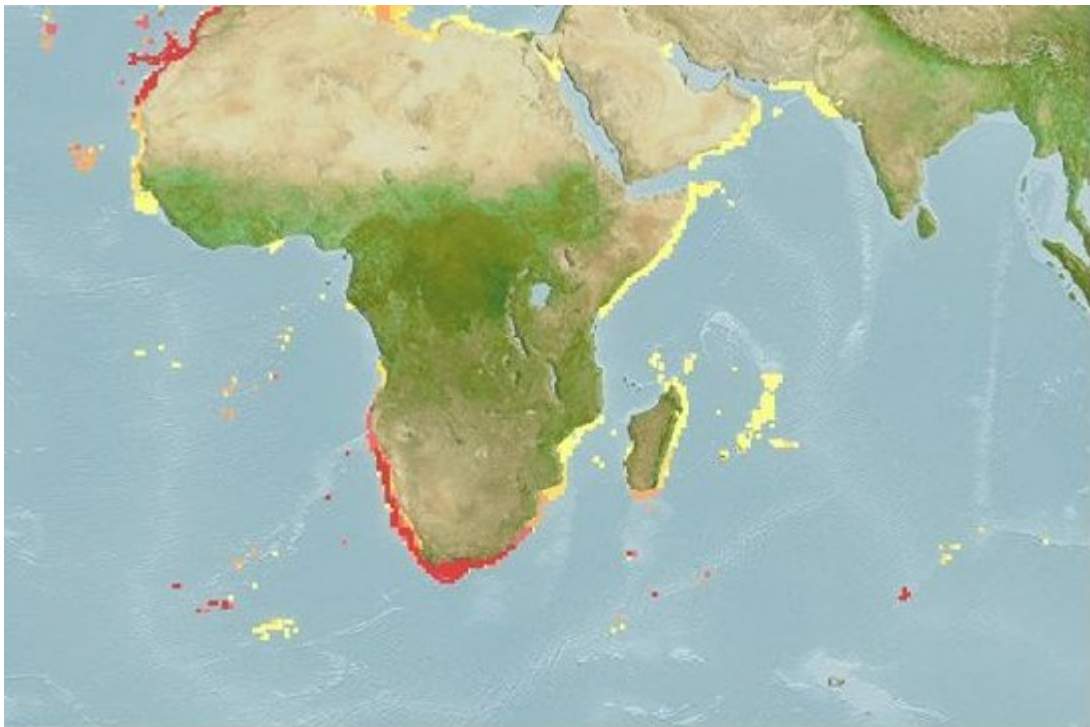


Figure B.41: Natural Habitat of Butter Snook

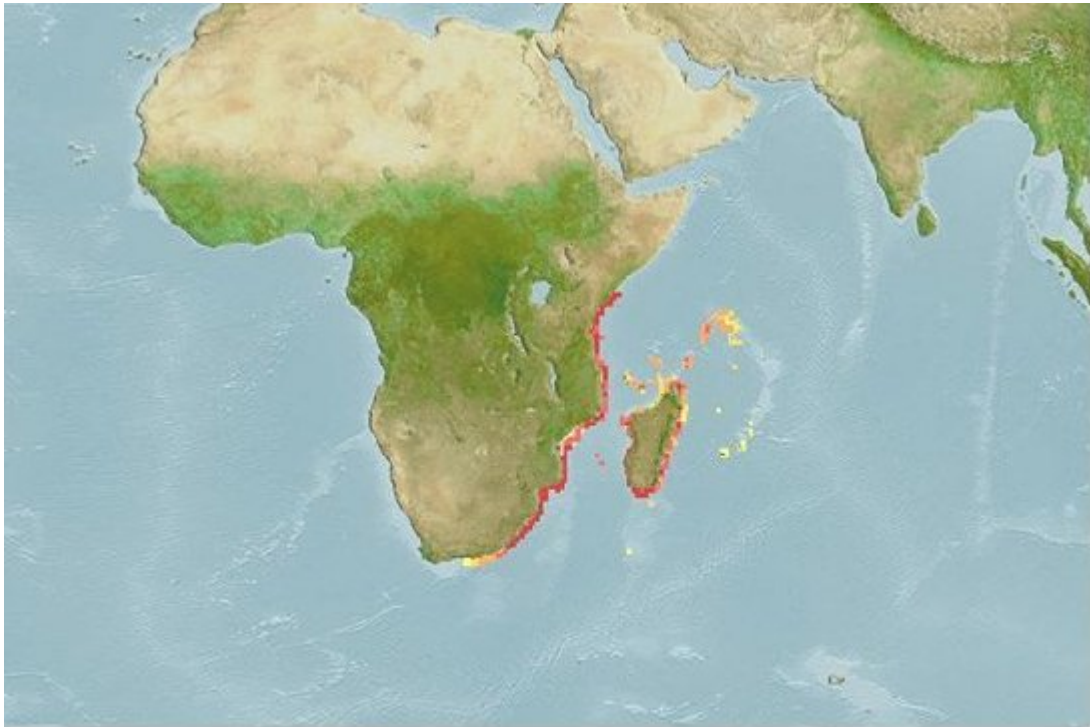


Figure B.42: Natural Habitat of Natal Snoek

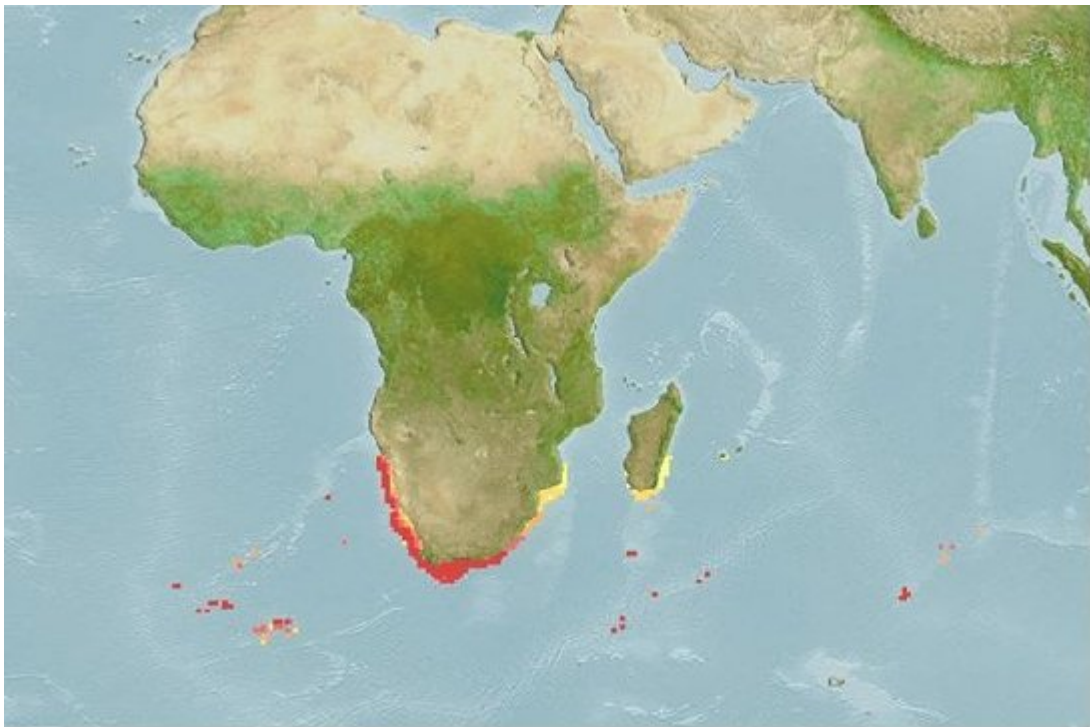


Figure B.43: Natural Habitat of Snoek

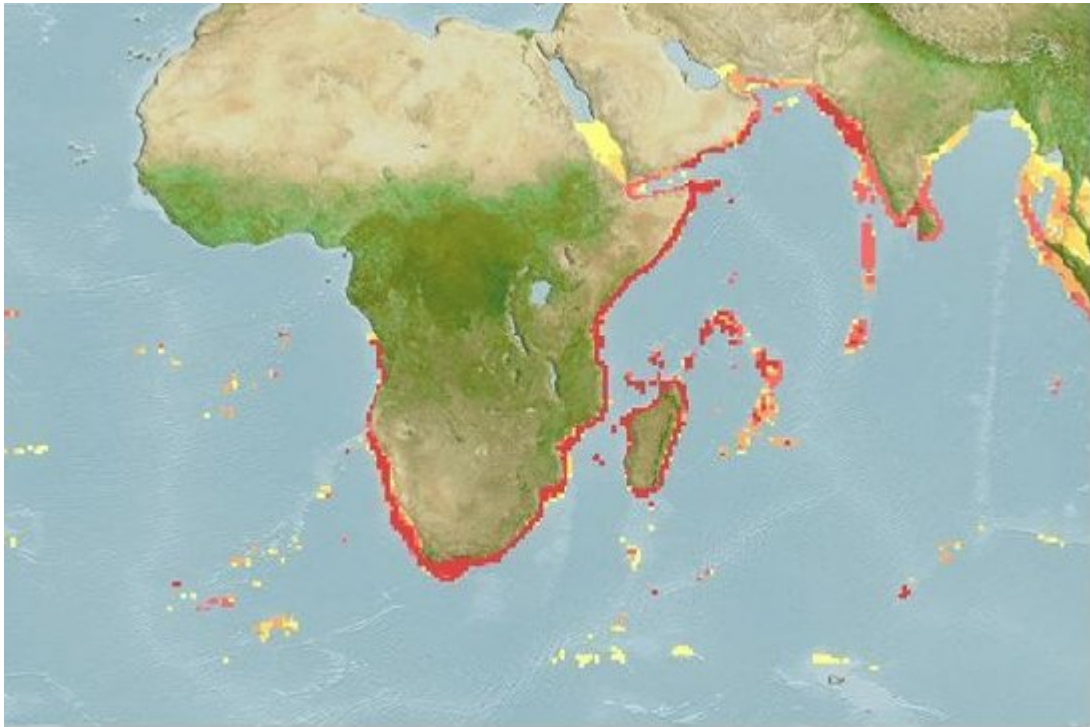


Figure B.44: Natural Habitat of Cape Yellowtail

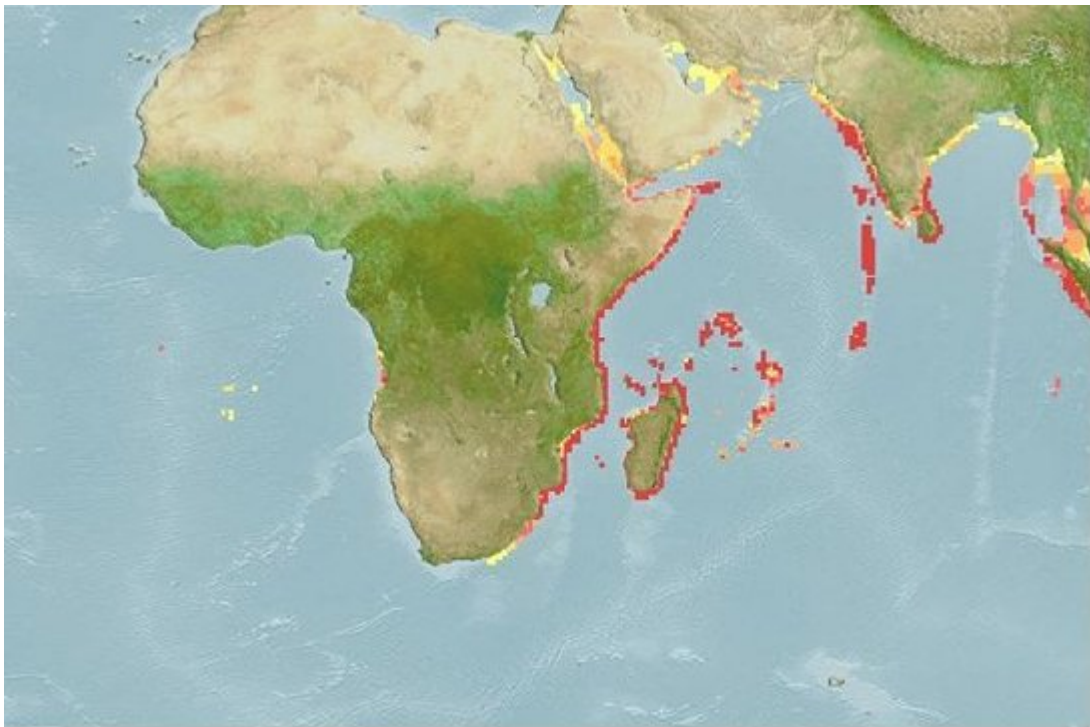


Figure B.45: Natural Habitat of Dusky Yellowtail

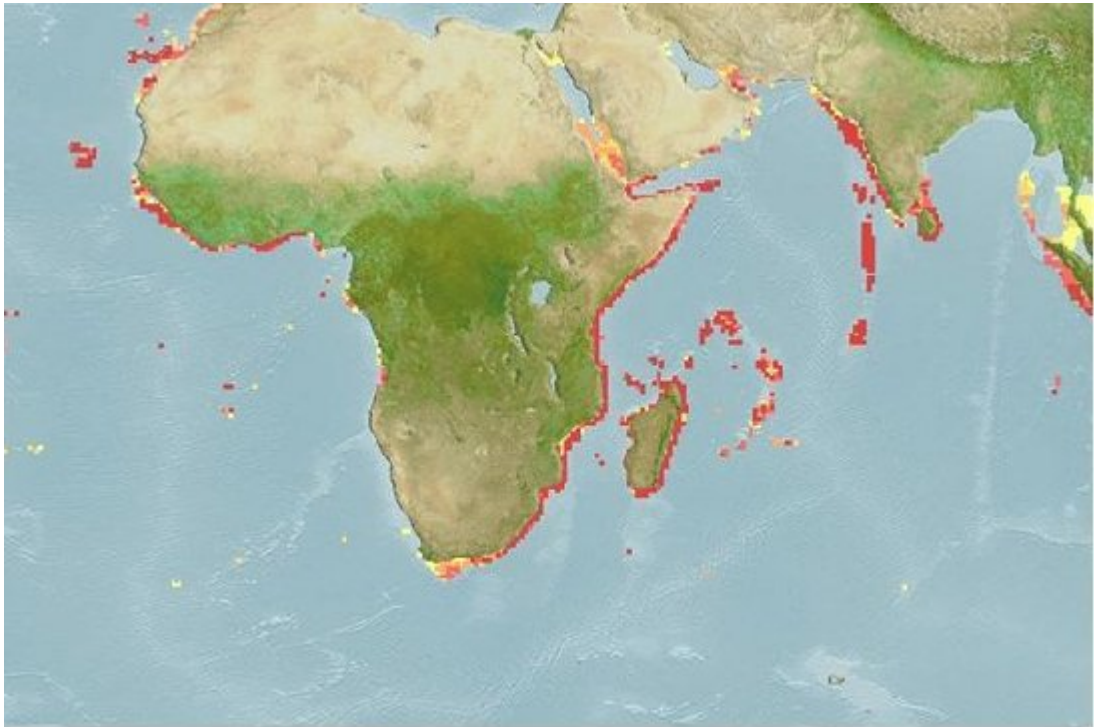


Figure B.46: Natural Habitat of Longfin Yellowtail

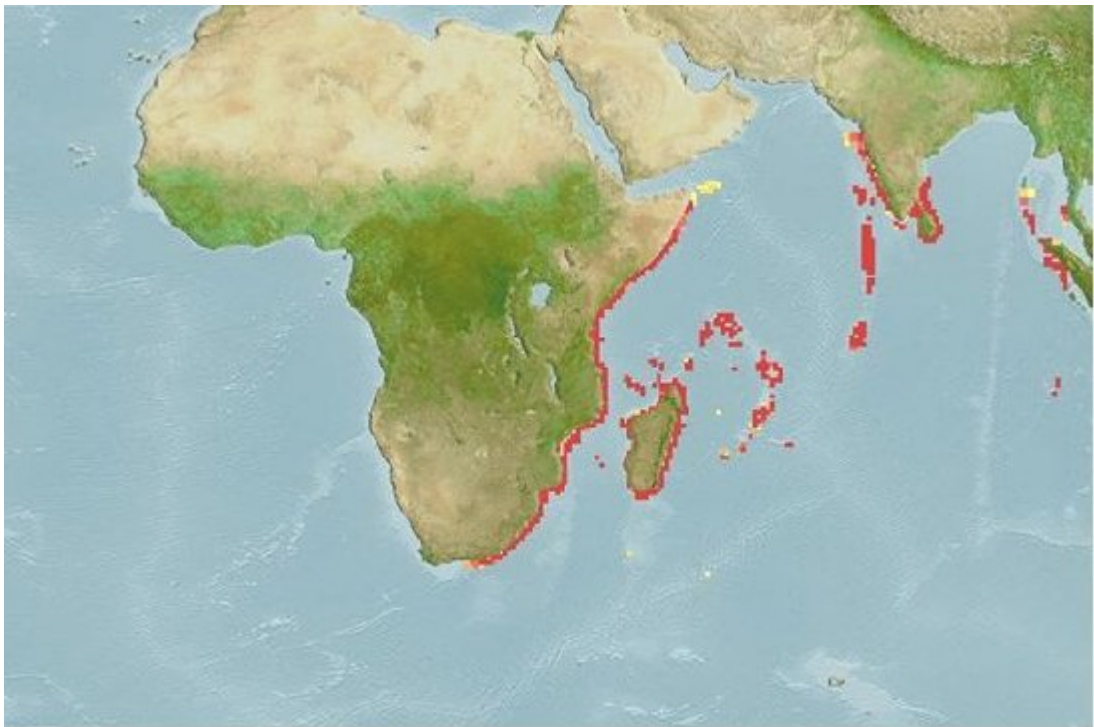


Figure B.47: Natural Habitat of Yellowtail Rockcod



Figure B.48: Natural Habitat of Banded Galjoen



Figure B.49: Natural Habitat of Koester

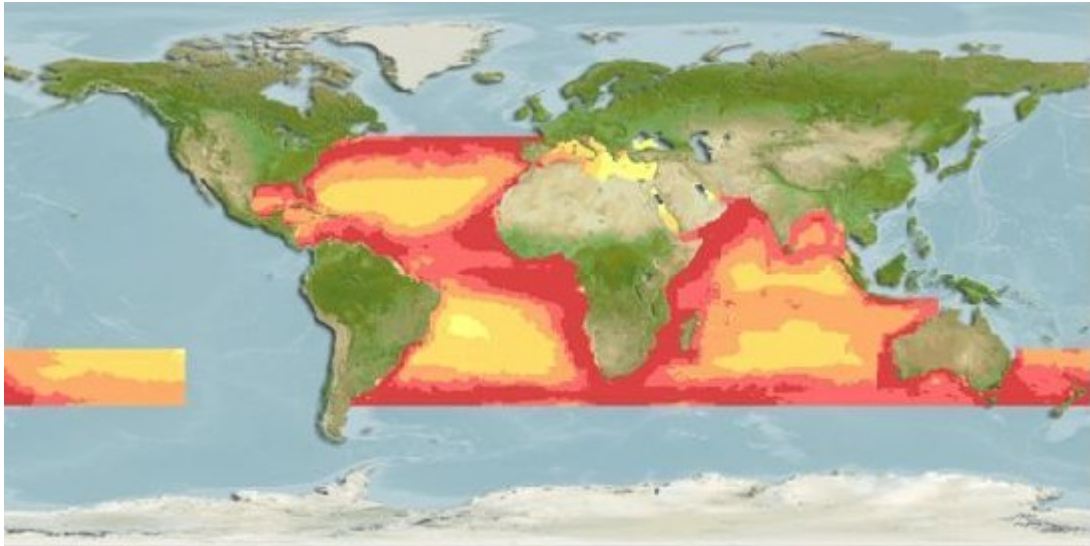


Figure B.50: Natural Habitat of Elf/Shad

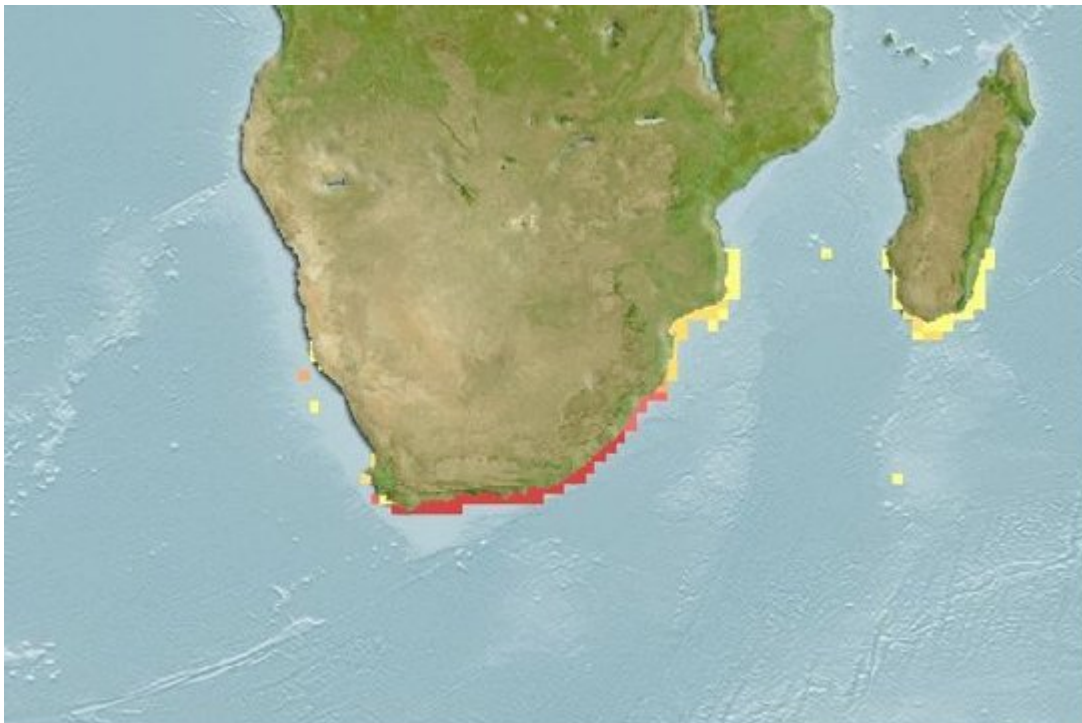


Figure B.51: Natural Habitat of Red Stumpnose

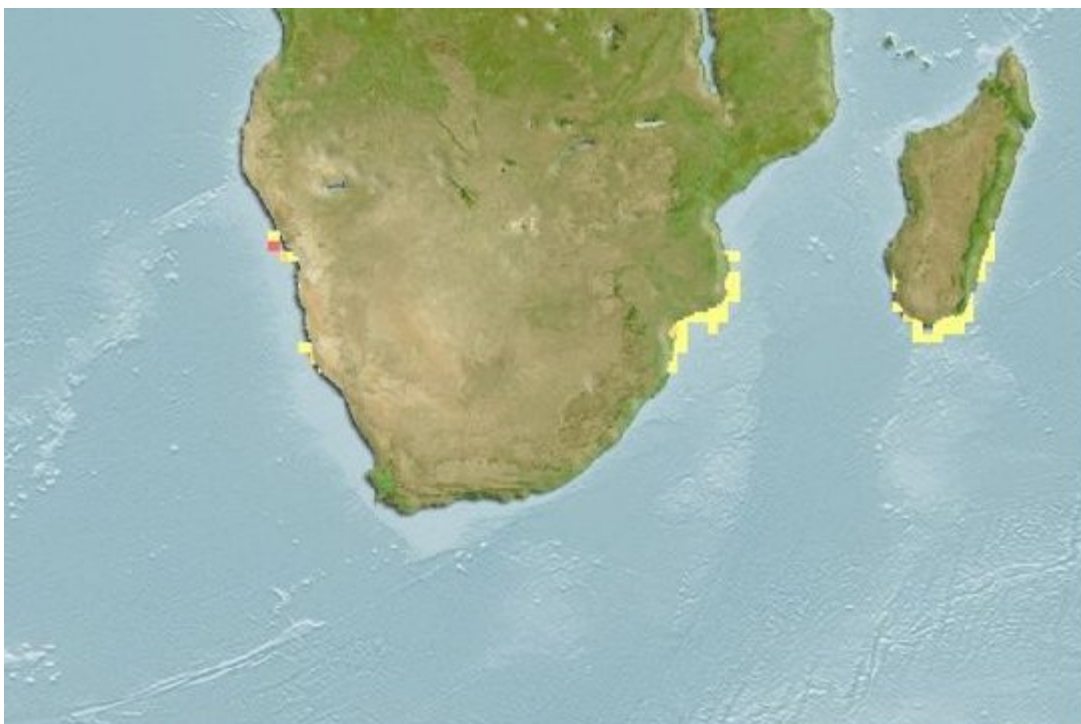


Figure B.52: Natural Habitat of Roman Seabream



Figure B.53: Natural Habitat of Bronze Seabream



Figure B.54: Natural Habitat of Cape Stumpnose

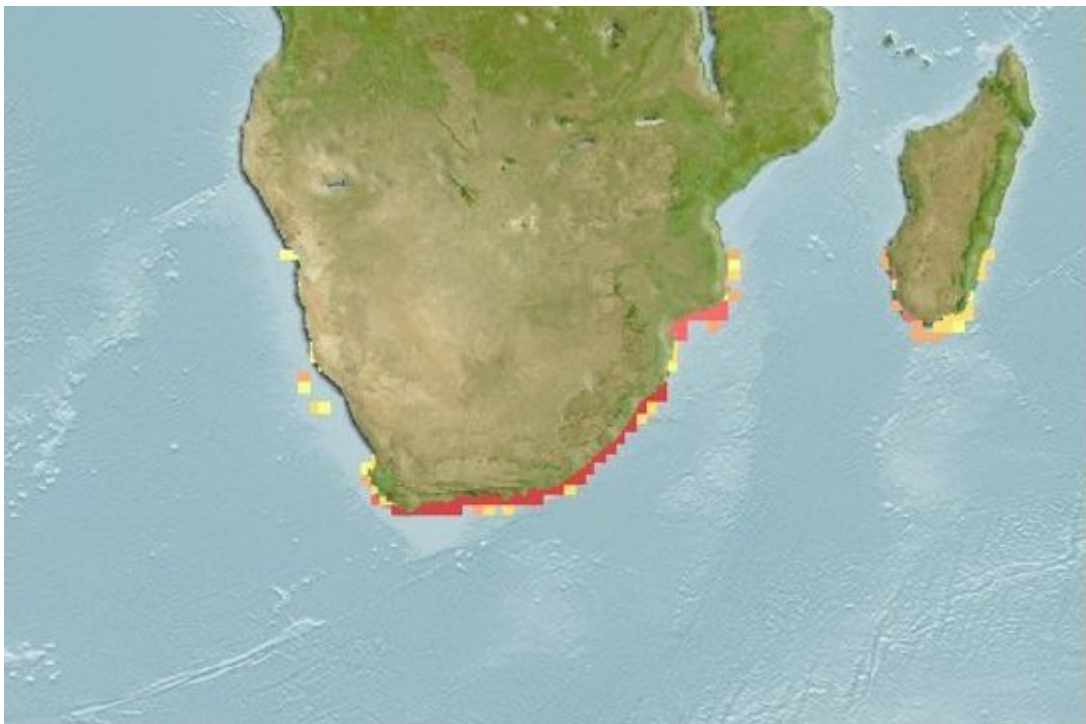


Figure B.55: Natural Habitat of Black Musselcracker



Figure B.56: Natural Habitat of White Musselcracker



Figure B.57: Natural Habitat of Carpenter Seabream



Figure B.58: Natural Habitat of Kabeljou/Silver Cob

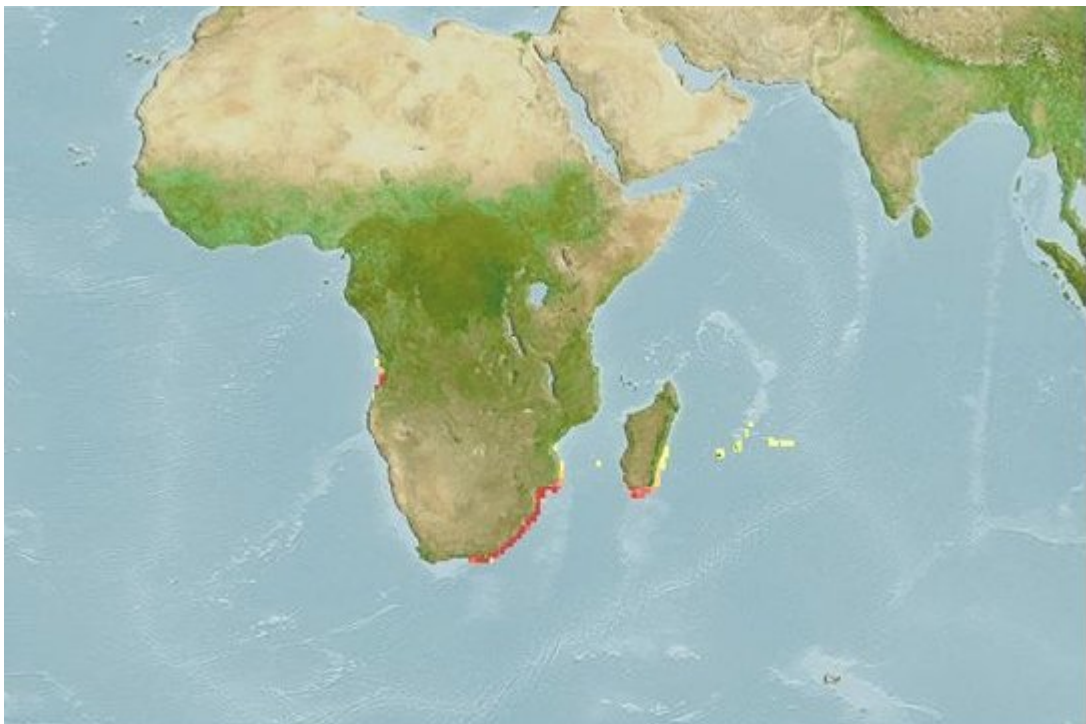


Figure B.59: Natural Habitat of Slinger Seabream

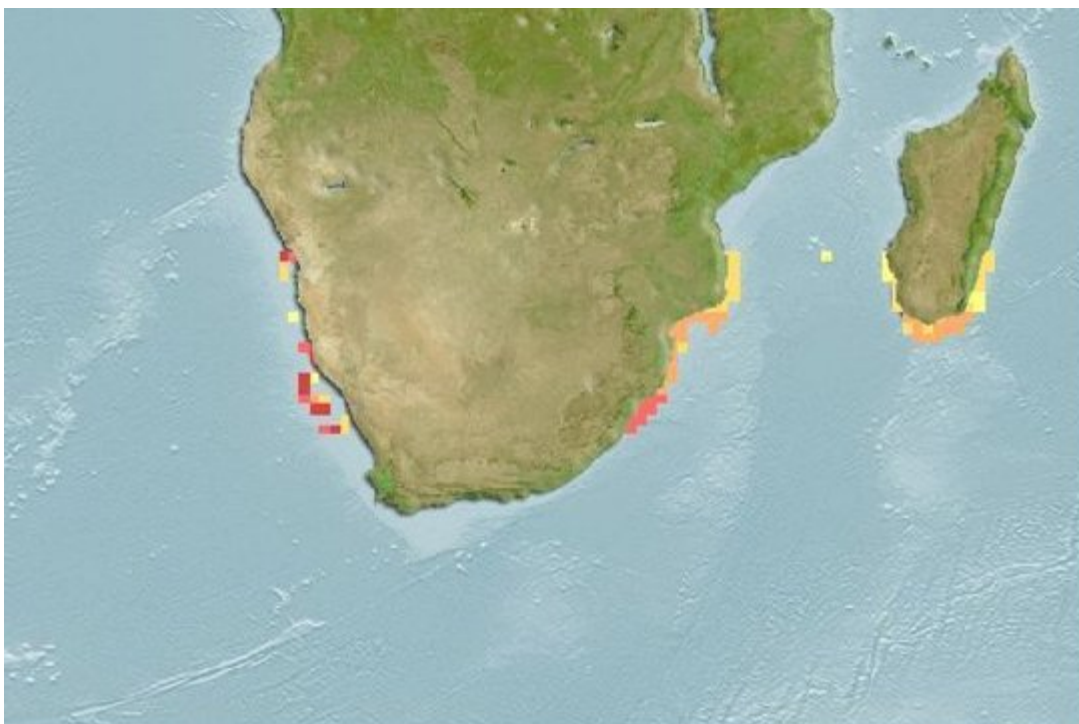


Figure B.60: Natural Habitat of White Steenbras

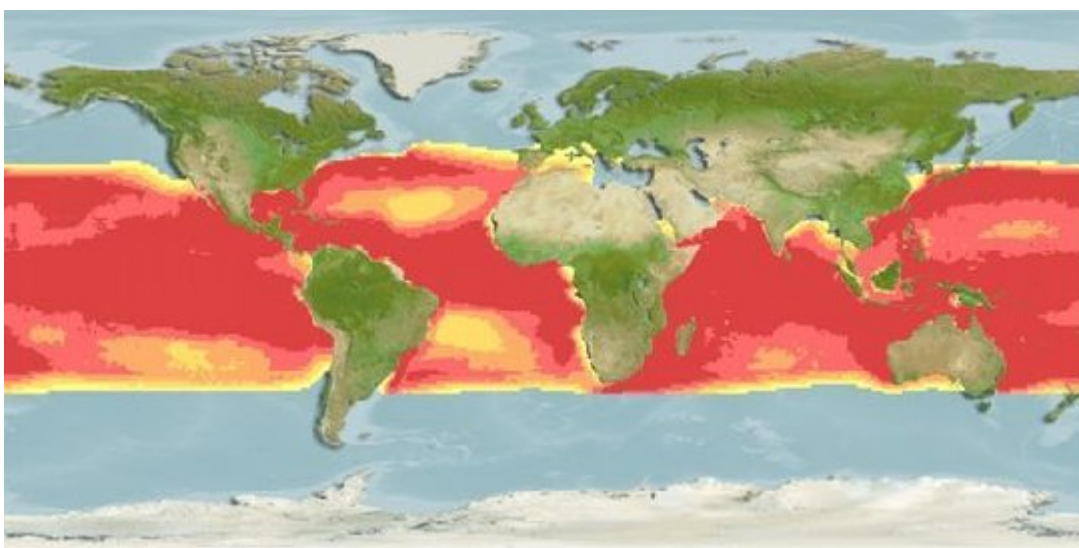


Figure B.61: Natural Habitat of Dorado/Mahi Mahi

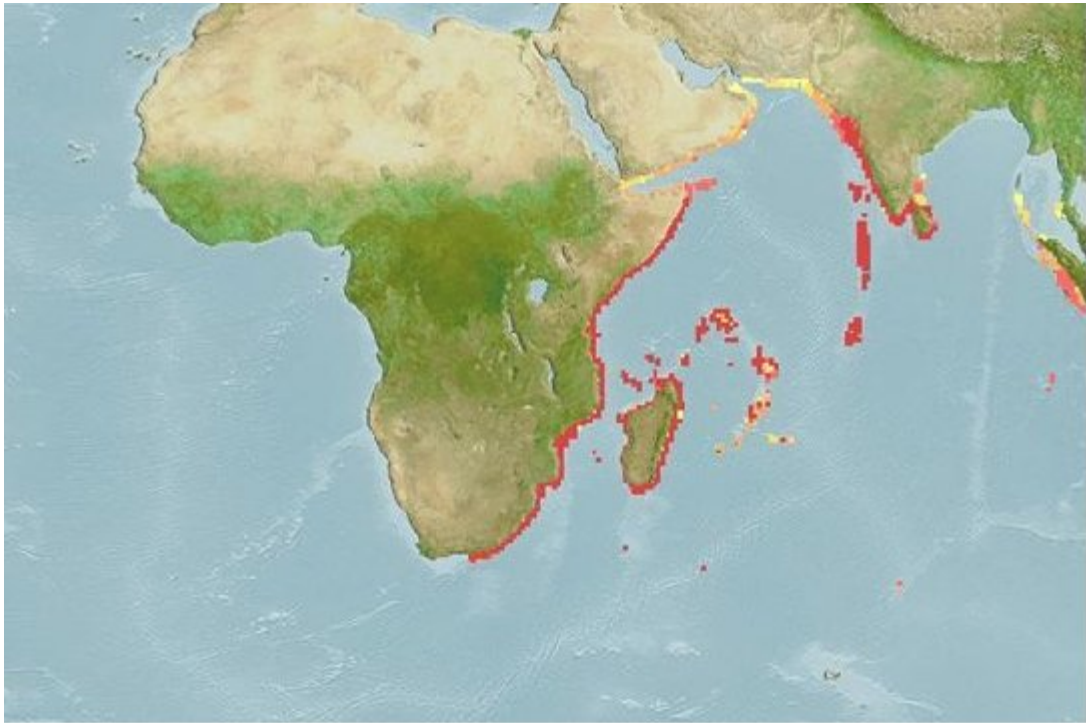


Figure B.62: Natural Habitat of Striped Bonito



Figure B.63: Natural Habitat of Atlantic Bonito

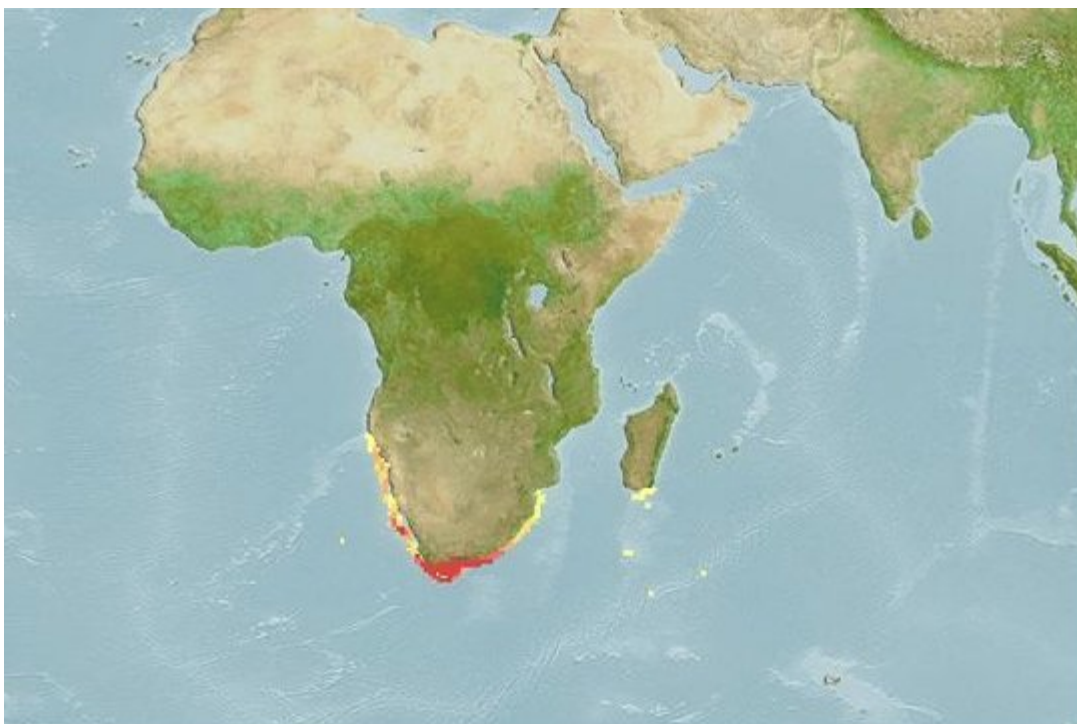


Figure B.64: Natural Habitat of South Coast Rock Lobster (*Palinurus gilchristi*): deep water (360m), Agulhas Bank

Sources:

- Marine Lobsters of the World
<http://nlbif.eti.uva.nl/bis/lobsters.php?menuentry=soorten&id=143>
- SeaLifeBase -
<http://www.sealifebase.org/summary/SpeciesSummary.php?id=15023>
- FAO - <http://www.fao.org/fi/oldsite/FCP/en/ZAF/body.htm>

NO MAP AVAILABLE

Natural Habitat of West Coast/Cape Rock Lobster (*Jasus lalandii*): inshore, shallow water (46m)

Sources:

- Encyclopedia - http://en.wikipedia.org/wiki/Jasus_lalandii
- Marine Lobsters of the World -
<http://nlbif.eti.uva.nl/bis/lobsters.php?menuentry=soorten&id=130>
- SeaLifeBase -
<http://www.sealifebase.org/summary/SpeciesSummary.php?id=14807>
- FAO - <http://www.fao.org/fi/oldsite/FCP/en/ZAF/body.htm>



Figure B.65: Natural Habitat of Chokker Squid



Figure B.66: Natural Habitat of Abalone (*haliotis midae*)



Figure B.67: Natural Habitat of European Blue Mussel

Appendix C

C. Minerals and Energy

Appendix C analyses marine activities associated with each of the primary marine-based mining industries in South Africa.

C.1. Annual Production

Annual amounts produced (2007 figures) are as follows^[58].

- Oil (crude petroleum): 2,559,000 barrels (158.987l/barrel => 406,847,733 litres)
- Natural Gas: 1,243,000 tons
- Diamonds (marine only): 155,000 carats
- Titanium: undisclosed amount (classified)^[58]
- Zirconium: undisclosed amount (classified)^[58]

C.2. Marine Activity

Marine activities associated with each of the primary marine-based mining industries mentioned above, can be summarised as flows.

C.2.1. Titanium

Titanium is predominantly found in beach sand^[59]. South Africa is the second-largest producer of titanium, producing 22% of the World's titanium^[60]. Titanium minerals are sourced from beach sand deposits found along the southern, eastern and north-eastern coasts, and additional deposits along the west coast^[60]. Three major mines recover the minerals from the sand^[60]:

- Richards Bay Minerals Tisand mine, located Richards Bay^[60];
- Exxaro Hillendale (KZN Sands) mine, located near Richards Bay^{[61][62]};
- Exxaro Namakwa Sands mine, located at Brand-se-Baai, 385km north of Cape Town^{[61][63]}.

Titanium mining involves strip-mining techniques, requiring dredging or dry mining^[64], depending on the nature of the deposits. Despite the use of a dredging vessel, the mines utilise on-land man-made freshwater ponds^[64]. The technique therefore does not expose vessels to off-shore marine environments.

C.2.2. Zirconium

Zircon mining is found in the same beach sand deposits and locations along the coast as for Titanium. The same three mines used for titanium extraction are used to extract the zirconium from its source; zirconium is a co-product of titanium mining^[65]. South Africa produces in the order of 40% of the World's zirconium^[66].

Since zirconium is mined as a co-product of titanium mining, the same dredging process is used during the collection of sand deposits, as is for titanium mining. As for titanium mining, the technique does not expose vessels to off-shore marine environments.

C.2.3. Diamonds (marine)

Marine diamond mining takes place along the western Atlantic seaboard, along the coasts of South Africa and Namibia^[67]. Namibia's marine diamond resources are the largest in the World, at an estimated 80 million carats^[67]. Marine mining involves excavating or drilling of the ocean floor, and operations are conducted from one of six specialised mining vessels^[67]. These operations take place up to 5km offshore, well within the Territorial Waters^[68].

C.2.4. Oil (crude petroleum)

Small oil and gas fields are located offshore, in the Bredasdorp Basin south of Mossel Bay and off the West Coast, near the Namibian border^[69]. Local oil production accounts for approximately 10% of total domestic needs^{[69][71]}. Oil is primarily sourced from the Oribi, Oryx and Sable oil fields located in the Bredasdorp Basin, using floating extraction and production facilities^{[69][71]}. The Bredasdorp Basin lies approximately 50 to 100nmi offshore, well within the Exclusive Economic Zone^[70]. Drilling is performed using drilling rigs, and

floating oil refineries and support vessels perform additional special functions^[71].

C.2.5. Natural Gas

Small oil and gas fields are located offshore, in the Bredasdorp Basin south of Mossel Bay and off the West Coast, near the Namibian border^{[69][70]}. Natural Gas is primarily sourced in gas pockets in the Bredasdorp Basin and the offshore Ibhubezi Gas Field near the Namibian border^{[69][71][70]}. As for crude petroleum, drilling and sourcing of Natural Gas is performed using drilling rigs. Gas is fed to refineries on-shore via pipelines^[71].



Figure C.1: Oil and Gas Fields in South Africa^[69]

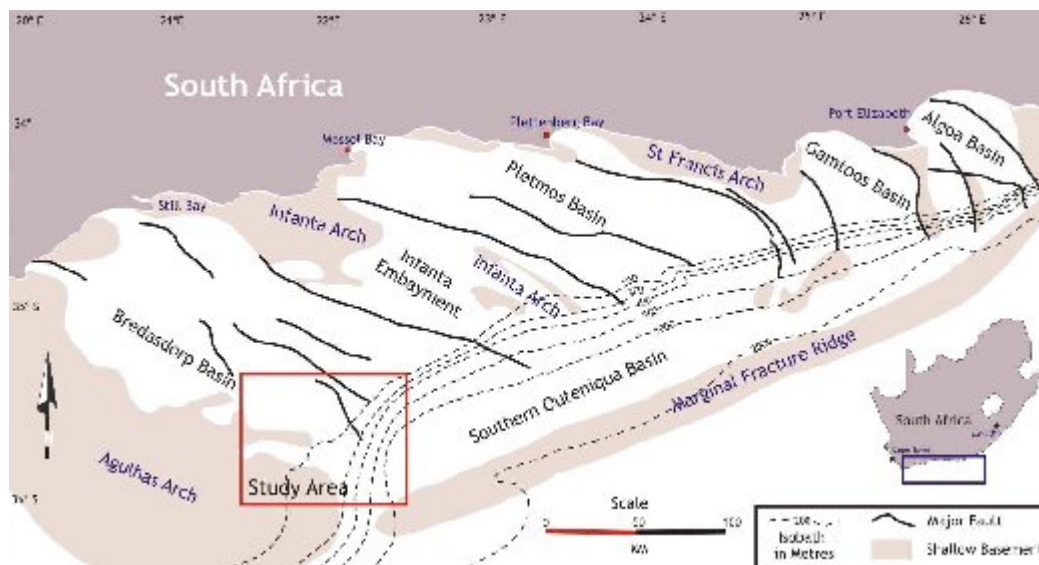


Figure C.2: The Bredasdorp Basin^[70]

Appendix D

D. Commercial Airline Routes

Appendix D provides a graphic summary of the routes flown by major commercial airlines to and from South Africa. Various routes traverse vast expanses of ocean adjacent our coasts, over our national marine claims and our national Search and Rescue Region.

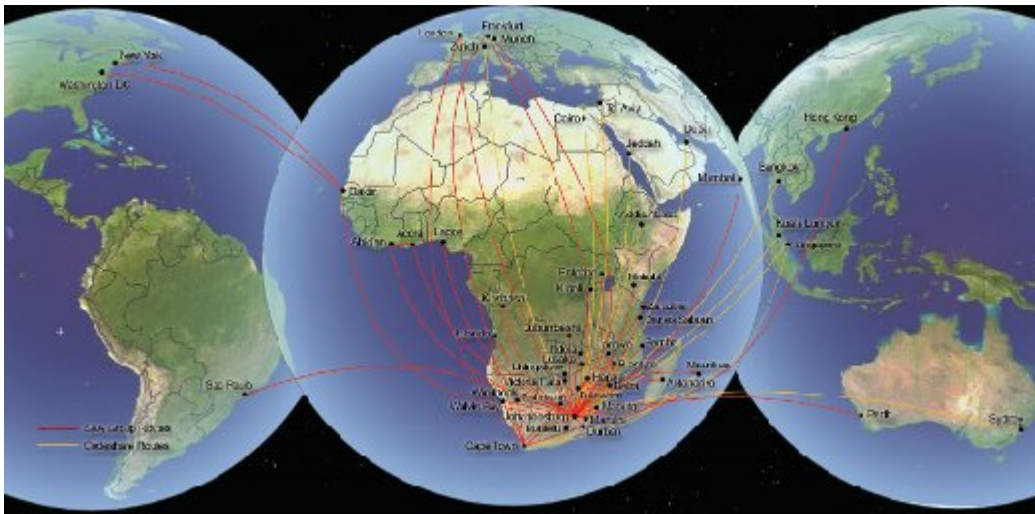


Figure D.1: SAA International

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/Africa/South_African_Airways.shtml)



Figure D.2: SAA Domestic

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/Africa/South_African_Airways_2.shtml)

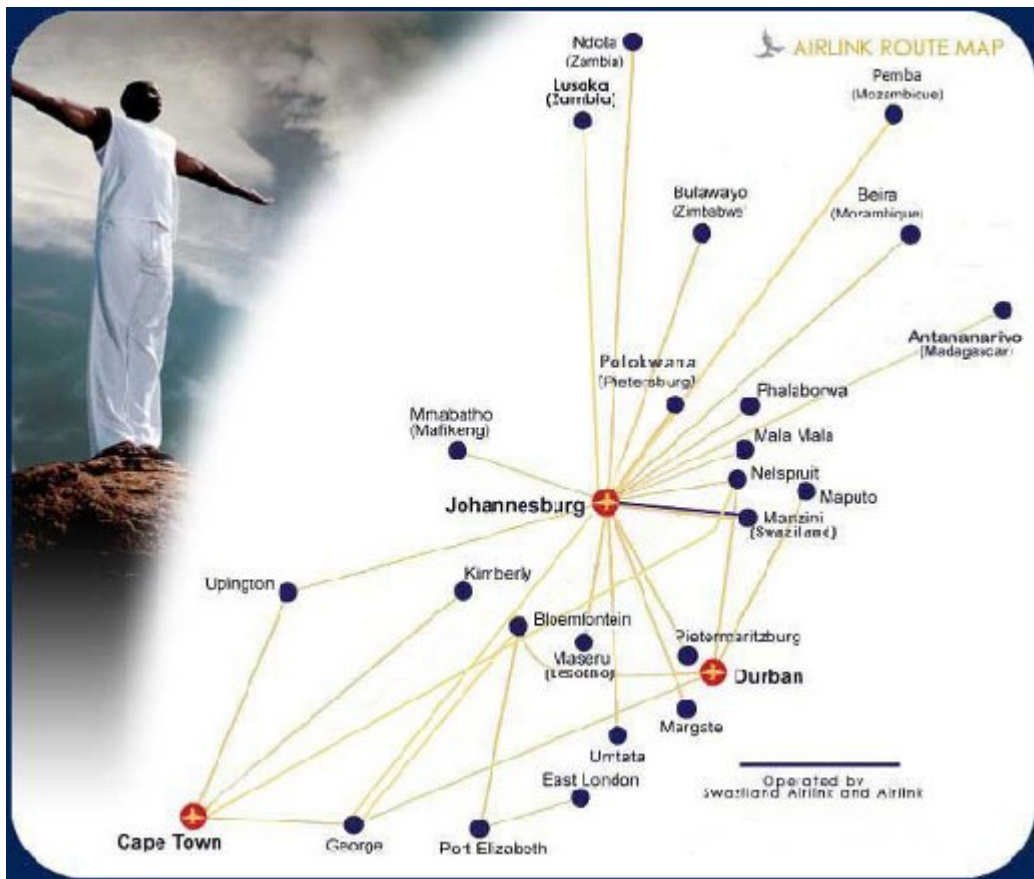


Figure D.3: SA Airlink

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/Africa/South_African_Airlink.shtml)



Figure D.4: SA Express

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/Africa/South_African_Express.shtml)



Figure D.5: Kulula

Source: www.airlineroutemaps.com

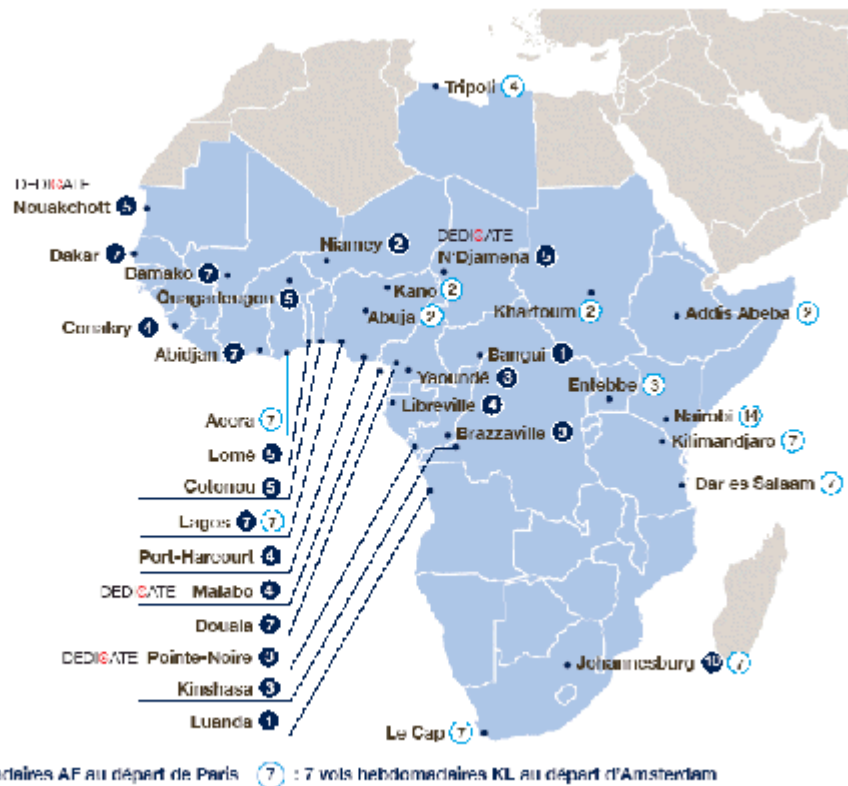
(http://www.airlineroutemaps.com/Africa/Kulula_south_africa.shtml)



Figure D.6: 1-Time

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/Africa/1Time_South_Africa.shtml)



7 : 7 vols hebdomadaires AF au départ de Paris 7 : 7 vols hebdomadaires KL au départ d'Amsterdam
 • AF et/ou partenaires + KL et/ou partenaires via Amsterdam

Figure D.9: Air France and KLM

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/Europe/Air_France_KLM_africa.shtml)

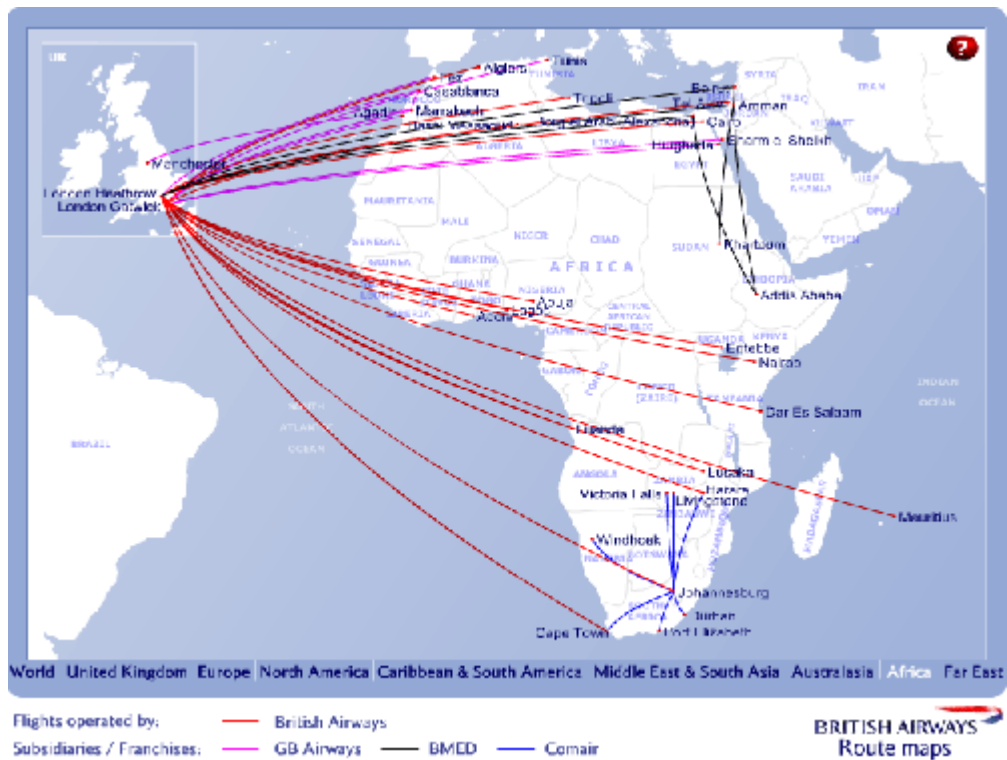


Figure D.10: British Airways

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/Europe/British_Airways_africa.shtml)



Figure D.11: Lufthansa

Source: www.lufthansa.com

(http://lufthansa.innosked.com/Default.aspx?lang_id=en&country=za)

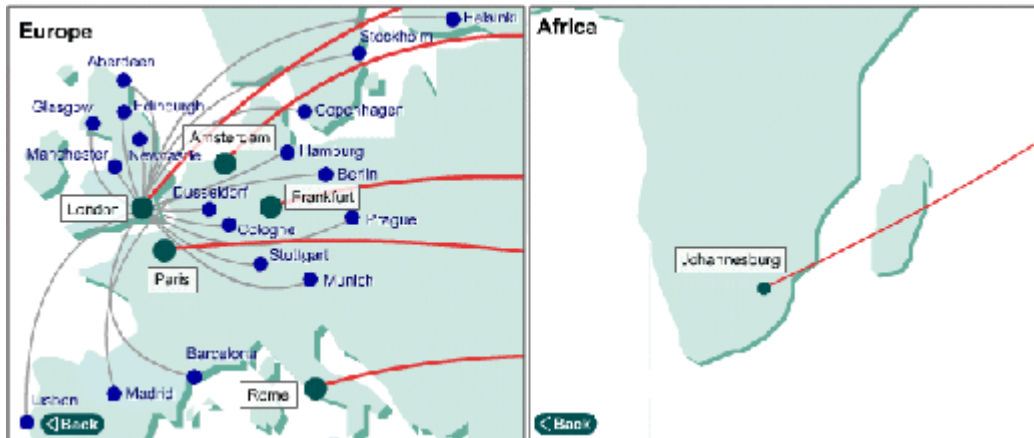


Figure D.12: Cathay Pacific

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/East_Asia/Cathay_Pacific_europe.shtml)



Figure D.13: Malaysia Airlines

Source: www.malaysiaairlines.innosked.com

([http://malaysiaairlines.innosked.com/\(S\(zossig45tfwlcofmnydqfj55\)\)/default.aspx?show=MAP&FromMap=no](http://malaysiaairlines.innosked.com/(S(zossig45tfwlcofmnydqfj55))/default.aspx?show=MAP&FromMap=no))



Figure D.14: Singapore Airlines

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/East_Asia/Singapore_Airlines_west_asia_africa.shtml)



Figure D.15: Qatar Airways

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/West_Asia/Qatar_Airways.shtml)



Figure D.16: Emirates

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/West_Asia/Emirates_asia_africa.shtml)

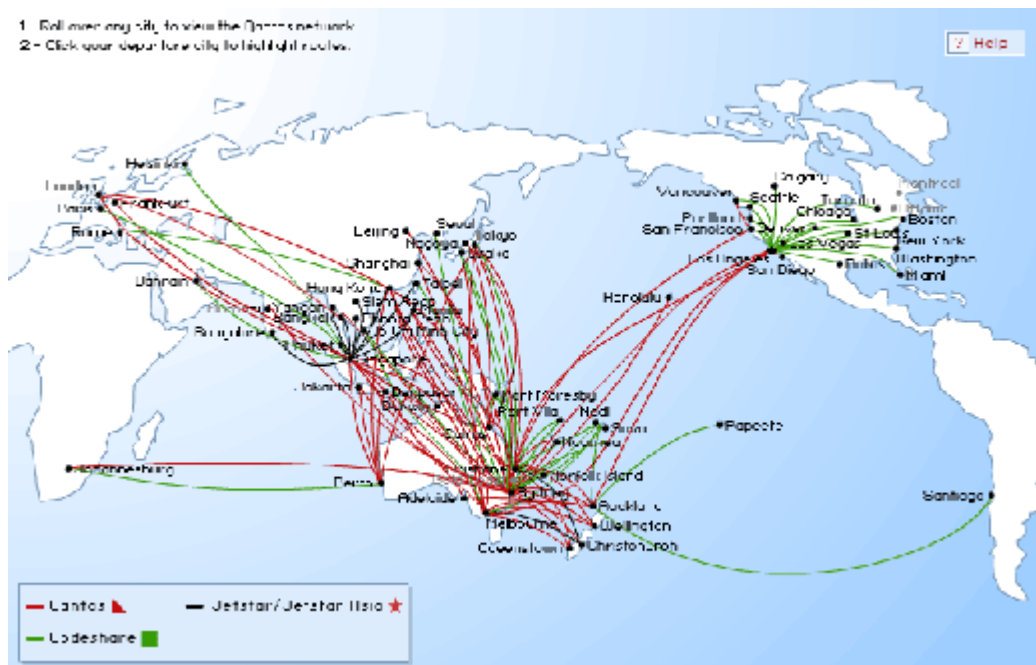


Figure D.17: Quantas

Source: www.airlineroutemaps.com

(http://www.airlineroutemaps.com/Oceania/Qantas_international.shtml)

Appendix E

E. Aeronautical Incidents over the Sea

Appendix E provides details of some of the most notable aeronautical incidents occurring in our oceans, recorded between 1967 and 2006.

- 13 March 1967, ZS-CVA, Vickers Viscount 818: crashed into the sea off East London^[119]
- 28 November 1987, ZS-SAS, Boeing 747-200B: crashed into the sea near Mauritius^[119]
- 31 May 1998, ZS-LIP, PA28-161: ditched into Gordons Bay^[120]
- 11 February 2001, ZS-WTW, Windlass Trike: ditched into sea at Umkomaas Beach^[121]
- 24 November 2002, N36GC, Glasair II S FT: forced landing on Marion Island due to severe ice build-up^[122]
- 23 November 2002, ZS-RNJ, SA 330J Puma: crash on deck of shipwreck near St Lucia^[122]
- 10 August 2002, ZS-MBL, Zlin Z-50LA, crashed into sea off Umdloti Beach^[122]
- 25 June 2002, ZU-BHA, Windlass Aquila: crashed into sea off Bazley Beach^[122]
- 14 March 2003, ZU-CUZ, Jabiru SP: crashed into sea off St Francis Bay^[123]
- 10 June 2006, ZU-ARI, Windlass Aquila,: crashed into the sea near Dwesa Nature Reserve^[124]
- 5 June 2006, ZS-VDC, Flight Star: ditched into sea at Bonza Bay^[124]

- 17 January 2006, ZS-RXA, Robinson R22 Beta II: crashed into the sea off Cape Point^[124]

Appendix F

F. National RSC's and Secondary RSC's

Appendix F provides a summary of the national RSC's and their Secondary RSC's.

F.1. RSC 1: Port Control Walvis Bay

Responsibility Region: From the Kunene River to the Orange River^[192].

Secondary RSC's^[192]:

- Namibia NSRI

F.2. RSC 2: Port Control Saldanha Bay

Responsibility Region: From the Orange River to East-West line dividing Dassen Island Lighthouse^[192].

Secondary RSC's^[192]:

- Saldanha Bay NSRI
- Port Nolloth NSRI

F.3. RSC 3: Port Control Cape Town

Responsibility Region: From the East-West line dividing Dassen Island Lighthouse to Cape Infanta^[192].

Secondary RSC's^[192]:

- NSRI Cape Town
- NSRI Melkbos
- NSRI Table Bay
- NSRI Bakoven
- NSRI Hout Bay

- NSRI Kommetjie
- NSRI Simonstown
- NSRI Strandfontein
- NSRI Gordons Bay
- NSRI Hermanus

F.4. RSC 4: Port Control Port Elizabeth

Responsibility Region: From Cape Infanta to Great Fish Point^[192].

Secondary RSC's^[192]:

- NSRI Mossel Bay
- NSRI Wilderness
- NSRI Knysna
- NSRI Plettenberg Bay
- NSRI St Francis Bay
- NSRI Port Elizabeth
- NSRI Port Alfred

F.5. RSC 5: Port Control East London

Responsibility Region: From Great Fish Point to Port St Johns^[192].

Secondary RSC's^[192]:

- None

F.6. RSC 6: Port Control Durban

Responsibility Region: From Port St Johns to the Tugela River^[192].

Secondary RSC's^[192]:

Appendix G

G. Maritime Search and Rescue Aircraft: Domestic

Appendix G provides a summary of aircraft currently available domestically for maritime Search and Rescue. Hypothetically any aircraft may be “co-opted” and tasked for such duties if the need arises and if the situation is drastic enough, but only a few of the total are regarded as specialised Search and Rescue assets. This summary focuses primarily on the latter.

G.1. South African Air Force (SAAF)

The South African Air Force have at their disposal the following aircraft equipped and deployable for maritime Search and Rescue operations^[219]:

Aircraft Type	No	Location
Denel Oryx M1/M2	47	17 SQN Pretoria (Inland) 15 SQN Durban (Coast) 19 SQN Hoedspruit (Inland) 22 SQN Cape Town (Coast)
Agusta Westland A109M	29	17 SQN Pretoria (Inland) 19 SQN Hoedspruit (Inland)
Douglas C47-TP MPA	5	35 SQN Cape Town (Coast)
Lockheed C-130BZ Hercules	9	28 SQN Pretoria (Inland)

Table G.1a: South African Air Force Aircraft Equipped and Deployable for Maritime SAR

The fixed wing aircraft types listed in table G.1a are capable of being equipped with either location markers and/or aid life supply canisters, and the crews operating them have received special SAR training. The rotary wing aircraft listed in Table G.1a are equipped, or can be equipped at short notice, with a rescue hoist and floatation gear, and the crews have also received SAR training. These aircraft form the core of the nation’s primary airborne SAR assets.

Table G.1b below lists other SAAF types potentially deployable for maritime SAR duties, should an emergency situation require additional aircraft to aid in a mission. These types are not specifically equipped, and crews have not necessarily received specific maritime SAR training. However, for the purpose

of this study, these types will be included in the analysis in lieu of the remote chance of being deployed for a maritime SAR task.

Aircraft Type	No	Location
Cessna C208A Caravan	11	41 SQN Pretoria (Inland)
CASA 212-200/300	4	44 SQN Pretoria (Inland)
CASA CN-235	1	44 SQN Pretoria (Inland)
Beech/Raytheon King Air 200/B200C	3	41 SQN Pretoria (Inland)
Beech/Raytheon King Air 300	1	41 SQN Pretoria (Inland)
Pilatus PC-12	1	41 SQN Pretoria (Inland)
MBB/Kawasaki BK117	7	15 SQN Durban (Coast) 15 SQN Port Elizabeth (Coast)

Table G.1b: South African Air Force Aircraft Potentially Deployable for Maritime SAR

G.2. South African Navy (SAN)

The South African Navy have at their disposal the following aircraft equipped and deployable for maritime Search and Rescue operations^[219]:

Aircraft Type	No	Location
Agusta Westland Super Lynx 300	4	22 SQN/SAN Frigates Cape Town (Coast)

Table G.2: South African Navy Aircraft Equipped and Deployable for Maritime SAR

G.3. South African Police Services (SAPS)

As mentioned in Chapter 7, the SAPS is not a primary supplier of maritime SAR aircraft. Table G.3 lists the types potentially deployable, in the remote event of this being a requirement. Asset numbers are 2008 figures, and are unconfirmed at the time of writing this thesis. The South African Police Services have at their disposal the following aircraft potentially deployable for maritime Search and Rescue operations^[220].

Aircraft Type	No	Location
MBB/Kawasaki BK117	2	SAPS Air Wing, countrywide
MBB BO105	12	SAPS Air Wing, countrywide
Eurocopter AS350 B3	13	SAPS Air Wing, countrywide
Pilatus PC-6 Porter	9	SAPS Air Wing, countrywide
Robinson R44 Raven II	6	SAPS Air Wing, countrywide
MDD MD500 (Hughes 369)	4	SAPS Air Wing, countrywide

Table G.3: South African Police Services Aircraft Potentially Deployable for Maritime SAR

G.4. The National Ports Authority (NPA)

The National Ports Authority, as operated by Acher Aviation, have at their disposal the following aircraft equipped and deployable for maritime Search and Rescue operations^{[31][221]}.

Aircraft Type	No	Location
Agusta Westland A109 K2	1	Durban/Richards Bay
Agusta Westland AW109E Power	1	Richards Bay
Agusta Westland A109S Grand	1	Durban

Table G.4: National Ports Authority Aircraft Equipped and Deployable for Maritime SAR

G.5. Titan Helicopter Group

Titan Helicopter Group have at their disposal the following aircraft equipped and deployable for maritime Search and Rescue operations^{[212][220]}.

Aircraft Type	No	Location
Sikorsky S-61N MkII	2	Cape Town, George
Sikorsky S-76A++ Spirit	2	Cape Town, George
Bell 212 Twin Huey	2	Cape Town, George
MBB BO105 CBS-5	1	Cape Town, George
Mil Mi-8 MTV	1	Cape Town, George
Mil Mi-8 P	1	Cape Town, George
Kamov Ka-32A	1	Cape Town, George
Kamov Ka-32C	1	Cape Town, George
Convair 580	2	Cape Town, George
Eurocopter EC120B	1	Cape Town, George

Table G.5: Titan Helicopter Group Aircraft Equipped and Deployable for Maritime SAR

Appendix H

H. RSE Analysis Tables

Appendix H tables the process followed to determine the key performance figures for existing aircraft, currently deployable for maritime Search and Rescue duties, domestic, foreign and unmanned. The resultant output from this Appendix appears as key performance figures in Tables 7.1, 8.1 and 9.1 in the actual thesis. Performance characteristics analysed were:

- Range (in nautical miles – nmi)
- Speed (maximum cruise, in knots – kn)
- Endurance (in hours and minutes)
- Communications range (in the case of UAV's) (in nautical miles – nmi)

Table H.1 provides the analysis for domestic-, Table H.2 for foreign-, and Table H.3 for unmanned aircraft.

H.1. Selection Logic

The following logic was used in the determination of the final figures for the above four characteristics. Five basic sources were identified where performance figures could be obtained. The five sources, in order of preference, are as follows.

H.1.1. Original Equipment Manufacturer (OEM)

Performance figures obtained from the OEM are usually presented in Data Sheets or Product Brochures. Although these figures are often a bit “optimistic”, the OEM figures were chosen as the primary source.

H.1.2. World Aircraft Information Files, Bright Star Publishing (WAIF)

Published in 218 weekly parts, from early 1998 until 2002, the World Aircraft Information Files (WAIF) is a comprehensive aeronautical reference work comprising 13 categories (“parts”) and over 1000 file subjects. WAIF is probably the closest reference alternative available to Jane’s All the World’s Aircraft. Part 12, entitled the “A to Z of Aircraft”, was used to determine additional performance figures for hardware unavailable from OEM’s. The Tables contain an extra column referencing the File and Sheet number for the data sourced from WAIF Part 12.

H.1.3. World Airnews Magazine

Two World Airnews Magazine articles were sourced to add performance figures for certain helicopters and turboprops not covered via OEM information or the WAIF reference work. For helicopter data, “Civilian Helicopter Directory 2009” (World Airnews, April 2009, Vol 37, No 2, pages 21 – 32) was used, while for certain turboprops “The World Airnews 2008 Corporate Turboprop Review” (World Airnews, May 2008, Vol 36, No 3, pages 17 – 32) was used. The Tables contain an extra column referencing the page number for data sourced from either of the publications.

H.1.4. Other Sources: World Wide Web

Failing any of the above three sources, the World Wide Web was used to source figures. Reputable Web Sites were identified for this task. This source was only used failing the first three.

H.1.5. Other Sources: Hardware Operators

As a last resort, operators of hardware equipment were contacted for performance figures “as reported”, or as derived from Operating Manuals. This was used as a final resort, due to the potentially long lead times to obtain information. This source was only used failing the first four.

H.2. Performance Data

The following is applicable to the actual performance data:

- In virtually all cases (unless where noted), Range and Speed were derived from the source material, and Endurance was calculated using these two figures. A notable variation from this procedure was applied for virtually all UAV performance figures, where Endurance and Speed was derived from source material, and Range calculated (as noted).
- In all cases, Maximum Cruise Speed was selected where source material provided both this and Maximum Speed. In certain cases, other speed figures (e.g. Long Range Cruise, Search Speed, etc) were used, as noted.
- For conversion between units, the following was used:
 - 1 mile [international] = 0.868 976 241 9 mile [nautical, international]
 - 1 kilometer = 0.539 956 803 46 mile [nautical, international]
 - 1 mile/hour (mph) = 0.868 976 241 91 knot
 - 1 kilometer/hour = 0.539 956 803 46 knot
 - 1 nautical mile/hour = 1 knot
- Final figures are rounded.

H.3. Tables

The following logic is applicable to the Tables:

- Available Data appears per aircraft type in GREEN coloured cells. Where no data is available from a specific source, the cell is coloured RED.

- Irrespective of how many available data sources there are per aircraft type, the logic for choosing which data to use is always as described above in H.1. If, for example, Aircraft Type A has available performance data from an OEM, the WAIF as well as the WWW, the OEM source will be used, as this is the first option, when available.
- The final selections appear in the last columns with the black and white header cells. These also contain the calculated “third performance element”, albeit Endurance, or Range (or Speed in a very few instances).

H.4. General

Additional information and details, pertaining to each Table and certain aircraft types, are listed below each applicable Table.

Finally, it should be remembered that printed/published performance figures in general are often estimated and could differ from actually tested figures. Additionally, in most cases not all figures are published for all possible conditions, weights, configurations and mission types. Consequently, the available data was either used or sound deductions were made to achieve the best possible outcomes. In many cases the results offered indicate “ultimate performance under pristine conditions”, however in the greater context of this thesis the results are more than adequate to solidify and add value to the outcome.

Aircraft TypeDomestic	OEM R	OEM S	WAIF R	WAIF S	File, Sheet	AN R	AN S	Page	Other R	Other S	R Final	S Final	T Final
Agusta Westland A109 LUH	500	153	289.4	142.5	889, 32						500	153	3h16m
Agusta Westland A109E Power	512	154				512	154	21			512	154	3h19m
Agusta Westland A109S Grand	424	156									424	156	2h43m
Beech King Air 200/B200C			1974.3	289.4	890, 10						1974.3	289.4	6h49m
Beech King Air 300			1960.4	315.4	890, 11						1960.4	315.4	6h12m
Bell 212 Twin Huey			236.4	100	890, 21				225	100	236.4	100	2h21m
CASA 212-200/300			n/a	191.2	891, 13				800	180	800	180	4h26m
CASA CN-235 (prototype)									2000	230	2000	230	8h42m
Cessna C208A Caravan	869	175	1371.2	184.2	891, 22						869	175	5h
Convair 580									1200	280	1200	280	4h17m
Denel Oryx M1/M2									827	120	827	120	6h53m
Douglas C47-TP MP&NT									1300	160	1300	160	8h7m
Eurocopter AS 350 B3	359	140				360	140	25			359	140	2h33m
Eurocopter EC 120B Colibri	383	120	394.5	123.4	893, 10	383	120	25			383	120	3h11m
Kamov Ka-32A									475	118.8	475	118.8	4h
Lockheed C-130BZ Hercules									2699.8	300	2699.8	300	9h
MBB BO105 CBS-5									600	134	600	134	4h28m
MBB/Kawasaki BK117			307.6	133.8	893, 8						307.6	133.8	2h17m
MD Helicopters MD-500E LEH	287	170	n/a	117.3	901, 13						287	170	1h41m
Mil Mi-8 MTV									567	116	567	116	4h53m
Mil Mi-8 P									737	116	737	116	6h21m
Pilatus PC-6 Porter	500	125									500	125	4h
Pilatus PC-12	1560	280				1573	280	37			1560	280	5h34m
Robinson R44 Raven II	304.1	117				346	117	32			304.1	117	2h35m
Sikorsky S-61N MkII									400.6	114.4	400.6	114.4	3h30m
Sikorsky S-76A++ Spirit	411	137				411	155	32			411	137	3h
Westland Super Lynx 300	280	132									280	132	2h7m

Table H.1: Performance Figure Analysis for Domestic Aircraft Deployable for Maritime Search and Rescue Tasks

Specifics pertaining to Table H.1

CASA 212-200/300

- Data source: SAAF Directorate Transport & Maritime Systems

CASA CN-235 (prototype)

- Data source: SAAF Directorate Transport & Maritime Systems

Convair 580

- Data source: Titan Helicopters Group

Denel Oryx

- Data source: SAAF Directorate Helicopter Systems Group
- Range option: with sponson tanks plus 4x ferry tanks

Douglas C47-TP MP&NT

- Data source: 35 Squadron C47-TP Flight Manual Part 5 Section 1 p 5-111

Kamov Ka-32A

- Data source: Titan Helicopters Group
- Range option: with auxiliary fuel tanks

Lockheed C-130BZ Hercules

- Data source: SAAF Product System Support Manager

MBB BO105 CBS-5

- Data source: Titan Helicopters Group
- Range option: with auxiliary fuel tanks

MD Helicopters MD-500E

- OEM source Range options: 3000lbs, 5000ft, C20R engine
- OEM source Speed options: Speed for best range, C20R engine

Mil Mi-8 MTV

- Data source: Titan Helicopter Group
- Range option: with auxiliary fuel tanks

Mil Mi-8 P

- Data source: Titan Helicopter Group

- Range option: with auxiliary fuel tanks

Pilatus PC-6 Porter

- OEM source Range option: No under-wing tanks

Sikorsky S-61N MkII

- Data source: Titan Helicopter Group

Sikorsky S-76A++ Spirit

- Data for S-76C++ used
- OEM source Range option: No reserve

Westland Super Lynx 300

- OEM source Range options: Empty cabin, standard tanks only

Aircraft Type _{Foreign}	OEM R	OEM S	WAIF R	WAIF S	File, Sheet	AN R	AN S	Page	Other R	Other S	R Final	S Final	T Final
Agusta Westland AW139	573	165				306	165	21			573	165	3h28m
Agusta Westland Merlin HM1	900	136	570.1	150.3	893, 11						900	136	6h37m
Alenia/ATR 42 MP Surveyor	2020	190									2020	190	10h37m
Alenia/ATR 72 ASW	1505	145									1505	145	10h22m
Alenia C27J Spartan	3200	325									3200	325	9h50m
BAe Nimrod MRA4									6000	442.8	6000	442.8	13h33m
Bell 214 ST			435.4	140	890, 21						435.4	140	3h6m
Bell 407	383	118				330	133	22			383	118	3h14m
Bell 412 EP	423	131				356	126	22			423	131	3h13m
Bell 427	400	133				390	138	22			400	133	3h
Bell 429	350	142				350	142	22			350	142	2h27m
Bell/Agusta BA 609	700	275				750	275	22			700	275	2h32m
Bell/Boeing MV-22B Osprey	1800	250									1800	250	7h12m
Bell UH-1Y Venom	260	135									260	135	1h55m
Boeing P-8A Poseidon	3160	490									3160	490	6h26m
Bombardier/DHC Dash 8 Q200	973	290									973	290	3h21m
Bombardier/DHC Dash 8 Q400	1526	361									1526	361	4h13m
CASA CN-235MP Persuader	2300	130									2300	130	17h41m
CASA C-295 Persuader	2400	145									2400	145	16h33m
Dassault Atlantique ATL2			4900.2	299.8	892, 2				4900	349.3	4900.2	299.8	16h20m
Dassault Falcon 900 MPA									4100	496.1	4100	496.1	8h15m
Embraer P-99 (EMB 145 MP)	2050	444.1	n/a	444.1	893, 3						2050	444.1	4h36m
Eurocopter AS 332 L2 Super Puma						446	150	26			446	150	3h
Eurocopter AS 365 N3 Dauphin	427	145				428	145	26			427	145	3h
Eurocopter AS 532 SC Cougar	492	136									492	136	3h37m
Eurocopter AS 555 Fennec	375	118	379.7	120.8	893, 9						375	118	3h10m
Eurocopter AS 565 Panther	427	145	n/a	147.7	893, 9						427	145	3h
Eurocopter EC 225 Super Puma	506	141.5				443	141	26			506	141.5	3h34m
Eurocopter EC 725 Cougar	692	141									692	141	4h54m
Eurocopter MH-65C Dolphin									300	165	300	165	1h49m
Fairchild-Dornier Do-228-101 MPA			1722.3	165.1	894, 5						1722.3	165.1	10h25m
Fokker 50 Maritime	2340	150									2340	150	15h36m
Ilyushin Il-38 May			4049.4	348.5	897, 4						4049.4	348.5	11h37m
Kaman SH-2G Super Seasprite	540	120	434.5	120	899, 2						540	120	4h30m
Lockheed HC-130J Hercules									5500	339	5500	339	16h13m
Lockheed P-3C Orion									4760	328	4760	328	14h30m
Lockheed CP-140 Aurora													
MD Helicopters MD-600N	423	115				380	130	28			423	115	3h40m
NH Industries NH90 FSH/NFH	659	132									659	132	5h
Reims-Cessna F406	1200	246									1200	246	4h52m
Shaanxi Y-8X MPA	4211	350									4211	350	12h1m
Sikorsky CH-148 Cyclone (MH-92)	525	137									525	137	3h49m
Sikorsky CH-53E Super Stallion									1119.9	150.1	1119.9	150.1	7h27m
Sikorsky MH-53E Sea Dragon									1050	150	1050	150	7h
Sikorsky MH-60T Jayhawk									300	170	300	170	1h45m
Sikorsky S-70B Sea Hawk	450	146									450	146	3h4m
Tupolev Tu-142M Bear-F									6775	500	6775	500	13h33m

Table H.2: Performance Figure Analysis for Foreign Aircraft Deployable for Maritime Search and Rescue Tasks

Specifics pertaining to Table H.2

Agusta Westland Merlin HM1

- OEM source Range options: 2 engine cruise, 0lbs

Alenia/ATR 42 MP Surveyor

- OEM source Range option: Ferry range
- OEM source Speed option: Max range cruise speed

Alenia/ATR 72 ASW

- OEM source Range deduction: At 100nmi from Base: 9hrs at 145 kn = 1305nmi + 200nmi = 1505nmi
- OEM source Speed option: Patrol speed

Alenia C27J Spartan

- OEM source Range options: Ferry range, 0lbs

BAe Nimrod MRA4

- Data source: WWW, <http://www.armedforces.co.uk/projects/raq3f561ff8f3fb4>

Bell 407

- OEM source Range options: 4000lbs, 4000ft, Long Range Cruise (LRC)

Bell 412 EP

- OEM source Range options: 9500lbs, 5000ft, LRC

Bell 429

- OEM source Range options: 5500lbs, Sea Level (SL), LRC

Bell/Boeing MV-22B Osprey

- OEM source Range options: Self-deploy, 3MAT, 0lbs

Bell UH-1Y Venom

- OEM source Range options: 2182lbs, 3000ft
- OEM source Speed option: LRC

Boeing P-8A Poseidon

- OEM source Range deduction: 1200nmi + range covered in 4hrs at 490kn

Bombardier/DHC Dash 8 Q200

- OEM source Range option: Full pax (big brochure used)

Bombardier/DHC Dash 8 Q400

- OEM source Range option: Full pax (big brochure used)

CASA CN-235MP Persuader

- OEM source Range deductions and options: Max transit distance x2, 0 search time, 0 search distance
- OEM source Speed deduction: At 200nmi from Base: 10 hr endurance, 1300nmi search distance = 130kn

CASA C-295 Persuader

- OEM source Range deduction and options: Max transit distance x2, 0 search time, 0 search distance
- OEM source Speed deduction: At 200nmi from Base: 10 hr endurance, 1450nmi search distance = 145kn

Dassault Falcon 900 MPA

- Multiple sources:
 - Falcon 900 MPA ~ Falcon 900DX: <http://www.dassault-aviation.com/en/defense/multi-mission-falcon/main-features.html?L=1>
 - Falcon 900DX performance pt 1: <http://www.dassaultfalcon.com/aircraft/900dx/performance.jsp>

- Falcon 900DX performance pt 2: <http://www.airliners.net/aircraft-data/stats.main?id=175>

Embraer P-99 (EMB 145 MP)

- OEM source Range options: 0 pax, 0lbs, (taken from ERJ 145LR data sheet)
- Speed source: Use WAIF info for ERJ 145

Eurocopter MH-65C Dolphin

- Data source: United States Coast Guard (USCG) Article

Fokker 50 Maritime

- OEM source Range option: Ferry range with pylon tanks
- OEM source Speed option: Search speed
- Endurance calculated by using Patrol Fuel Consumption (479 kg/h) and maximum fuel load with pylon tanks (7,511 kg)
- Range calculated from endurance and search speed

Lockheed HC-130J Hercules

- Data source: USCG fact sheet

Lockheed P-3C Orion

- Source data: WWW, http://www.navy.mil/navydata/fact_display.asp?cid=1100&tid=1400&ct=1

MD Helicopters MD-600N

- OEM source Range options: 3100lbs, 5000ft
- OEM source Speed options: Speed for best range, 3100lbs, 5000ft

NH Industries NH90 FSH/NFH

- OEM source Range option: Ferry range

- OEM source Speed option: Economical cruise

Sikorsky CH-148 Cyclone (MH-92)

- OEM source Range option: 0 pax/payload
- Speed source: WWW, http://en.wikipedia.org/wiki/CH-148_Cyclone
- WWW source Speed option: Cruise Speed

Sikorsky CH-53E Super Stallion

- Data source: WWW, <http://www.naval-technology.com/projects/ch-53e/specs.html>

Sikorsky MH-53E Sea Dragon

- Data source: WWW, http://www.navy.mil/navydata/fact_display.asp?cid=1200&tid=400&ct=1

Tupolev Tu-142M Bear-F

- Data source: WWW, <http://www.bharat-rakshak.com/NAVY/aviation/aircraft/119-tupolev-tu142m.html>

Aircraft Type ^{Unmanned}	OEM CR	OEM R	OEM S	Other CR	Other R	Other S	CR Final	R Final	S Final	T Final
AAI RQ-7B Shadow 200	68	540	90				68	540	90	6h
BAe HERTI				Range max	2250	90	Range max	2250	90	25h
Bell TR916 Eagle Eye	100	800	200				100	800	200	4h
Boeing A160T Hummingbird		2250	112.5	110			110	2250	112.5	20h
Denel Dynamics Bateleur	Satcom	2430	135				Satcom	2430	135	18h
EADS ORKA-1200				Tactical (110)	842	105.3	Tactical (110)	842	105.3	8h
Elbit Hermes 450	108 (std)	1400	70				108 (std)	1400	70	20h
Elbit Hermes 1500	108 (std)	2080	80				108 (std)	2080	80	26h
General Atomics RQ-1/MQ-1 Predator		4800	120	Satcom			Satcom	4800	120	40h
General Atomics MQ-9 Reaper	Satcom	7200	240				Satcom	7200	240	30h
General Atomics Mariner	Satcom	7100	157				Satcom	7100	157	45h13m
IAI Heron TP (Eitan)	Satcom				7200	200	Satcom	7200	200	36h
IAI/EADS Eagle 1/Heron 1/Harfang	Satcom	2400	80				Satcom	2400	80	30h
IAI/EADS Eagle 2	Satcom	4320	180				Satcom	4320	180	24h
IAI/PUI RQ-2 Pioneer				100	495	110	100	495	110	4h30m
InSitu/Boeing ScanEagle	Range max	980	49				Range max	980	49	20h
Northrop Grumman MQ-8B Fire Scout	110	880	110				110	880	110	8h
Northrop Grumman RQ-4A Global Hawk	Satcom	12000	343				Satcom	12000	343	35h
RUAG Ranger	97	630	70				97	630	70	9h
SAAB Skeldar V-200	81	350	70				81	350	70	5h
Sagem Sperwer B	108				972	81	108	972	81	12h
Schiebel Camcopter	97	330	55				97	330	55	6h
Swift Killer Bee	50	972	64.8				50	972	64.8	15h
Warrior/Aero-Marine Gull 68	100	1124	100				100	1124	100	11h14m

Table H.3: Performance Figure Analysis for Unmanned Aircraft Deployable for Maritime Search and Rescue Tasks

Specifics pertaining to Table H.3

General

- Neither World Aircraft Information Files (WAIF), nor any of the two World Airnews articles referenced, contain any performance data for Unmanned Aerial Vehicles. These columns have therefore been removed from Table A-3.

AAI RQ-7B Shadow 200

- Range calculated from Speed (90kn) and Endurance (6h)

BAe HERTI

- Data source for Communications Range: WWW, <http://www.baesystems.com/ProductsServices/HERTI.html>
- Data used for other data: WWW, <http://www.flightglobal.com/directory/uav/bae-systems-3199/herti-xpa-1b-7478.html>

- Range calculated from Speed (90kn) and Endurance (25hrs)

Bell TR916 Eagle Eye

- Range calculated from Speed (200kn) and Endurance (4hrs)

Boeing A160T Hummingbird

- Speed calculated from Range (2250nmi) and Endurance (20hrs)
- Communications range is estimated to 110nmi, as it is understood the A160T does not incorporate a satellite link

Denel Dynamics Bateleur

- General: Not an International UAV (although being co-developed with International parties), this National is still in development, and estimated performance figures have been included for comparison only.
- Range calculated from Max cruise speed and min endurance (18 hrs)
- OEM source Speed option: Max cruise speed

EADS ORKA-1200

- Data source for Communications Range: WWW, http://www.aviationweek.com/shownews/03paris/aircraft3_05.htm
- Data used for other data: WWW, http://www.eads.com/1024/en/pressdb/archiv/2003/2003/en_20030614_lbsysde.html
- Range calculated from Speed (195km/h = 105.3kn) and Endurance (8hrs)

Elbit Hermes 450

- Range calculated from Speed (70kn) and Endurance (20hrs)

Elbit Hermes 1500

- Range calculated from Speed (80kn) and Endurance (26hrs)

General Atomics RQ-1/MQ-1 Predator

- Data source for Communications Range: WWW, <http://www.airforce-technology.com/projects/predator/>
- Data used for other data: OEM source
- Range calculated from Speed (120kn) and Endurance (40hrs)

General Atomics MQ-9 Reaper

- Range calculated from Speed (240kn) and Endurance (30hrs)

General Atomics Mariner

- Speed calculated from maximum Endurance (45.2hrs) and Range (7100nmi)

IAI Heron TP (Eitan)

- Speed is estimated to be similar to similarly sized, -proportioned and -powered Reaper and Mariner – averaged to 200kn
- Range is calculated from endurance (36h) and Speed (200kn)

IAI/EADS Eagle 1/Heron 1/Harfang

- Range calculated from Speed (80kn) and Endurance (30hrs)

IAI/EADS Eagle 2

- Range calculated from Speed (180kn) and Endurance (24hrs)

IAI/PUI RQ-2 Pioneer

- Data source: WWW, <http://www.uavforum.com/vehicles/production/pioneer.htm>

InSitu/Boeing ScanEagle

- Range calculated from Cruise Speed (49kn) and Endurance (20hrs)

Northrop Grumman MQ-8B Fire Scout

- Range calculated from 6hrs @ 110kn + 220nmi

- Speed calculated from Total Endurance = 8hrs, with 6 hours for searching, which leaves 1hr to cover 110nmi = 110kn

RUAG Ranger

- Range calculated from Speed (70kn) and Endurance (9hrs)

SAAB Skeldar V-200

- Range calculated from Speed (70kn) and Endurance (5hrs)

Sagem Sperwer B

- OEM source available, but contains no relevant or useful performance data EXCEPT for communications range
- Data source used for other data: WWW, <http://www.army-technology.com/projects/sperwer-uav/specs.html>
- Range calculated from Speed (150km/h = 81kn) and Endurance (12hrs)

Schiebel Camcopter

- Range calculated from Cruise Speed (55kn) and Endurance (6hrs)

Swift Killer Bee

- Speed calculated from endurance (15hrs) and maximum range (972nmi)

Warrior/Aero-Marine Gull 68

- Endurance calculated from Range (1124nmi) and Speed (100kn)

Appendix I

I. Key Performance Requirement per Search Location

Appendix I provides the detail calculations and train of thought for the determination of the key performance requirements (speed, range and endurance) for each of six search locations. The following assumptions have been made in determination of these key performance requirements:

- Range is calculated along a straight line from a point on the coast up to the location limits (refer Figure 4.3).
- The effect of wind is ignored.
- It is assumed the asset will be capable of performing the entire mission at maximum cruise speed (transit and search).

I.1. Search Location 1: Territorial Waters (TW)

The key performance requirements for assets operating to the limits of this location are calculated and deduced as follows.

I.1.1. Location Boundaries_{TW}

From Shoreline to 12nmi offshore.

I.1.2. Speed_{TW}

The most important factor influencing the speed requirement is that the Search and Rescue asset must reach the search location limit within 6 hours (point 5.3.2). The minimum required cruise speed is calculated as follows:

$$V_{Cruise} = \frac{S_{TW}}{T_6}$$

$$V_{CruiseCalc} = \frac{12nmi}{6h}$$

$$V_{CruiseCalc} = 2nmi / h = 2kn$$

Considering that the lowest cruise speed for any Search and Rescue asset, as listed in Tables 7.1, 8.1 and 9.1, is 49 knots^[239], the very low calculated requirement of 2kn will be ignored. A cruise speed of at least 50kn will form the basis for this and all subsequent calculations.

The minimum required cruise speed is therefore accepted as:

$$V_{CruiseAcc} = 50nmi / h = 50kn$$

I.1.3. Range_{TW}

The total range is calculated as follows:

- +Distance from coast to TW limit
- +Distance traveled in 4 hours at accepted cruise speed
- +Distance from TW limit to coast
- +Distance traveled in 1 hour at accepted cruise speed

which equates to:

$$S_{Total} = 12 + (4 \times 50) + 12 + (1 \times 50)$$

$$S_{Total} = 274nmi$$

I.1.4. Endurance_{TW}

The total endurance is calculated as follows:

- +Travel time at accepted cruise speed from coast to TW limit
- +Maximum Search Time
- +Travel time at accepted cruise speed from TW limit to coast
- +1 hour emergency time

which equates to:

$$T_{Total} = \left(\frac{12nmi}{50nmi / h} \right) + 4 + \left(\frac{12nmi}{50nmi / h} \right) + 1$$

$$T_{Total} = 5.48h$$

$$T_{Total} = 5h \ 29m$$

I.2. Search Location 2: Contiguous and Maritime Cultural Zone (C&MCZ)

The key performance requirements for assets operating to the limits of this location are calculated and deduced as follows:

I.2.1. Location Boundaries_{C&MCZ}

From Shoreline to 24nmi offshore.

I.2.2. Speed_{C&MCZ}

The minimum required cruise speed is calculated as follows:

$$V_{Cruise} = \frac{S_{C\&MCZ}}{T_6}$$

$$V_{CruiseCalc} = \frac{24nmi}{6h}$$

$$V_{CruiseCalc} = 4nmi / h = 4kn$$

As explained in the previous sub-section for the Territorial Waters, the minimum required cruise speed is accepted as:

$$V_{CruiseAcc} = 50nmi / h = 50kn$$

I.2.3. Range_{C&MCZ}

The total range is calculated as follows:

- +Distance from coast to C&MCZ limit
- +Distance traveled in 4 hours at accepted cruise speed
- +Distance from C&MCZ limit to coast
- +Distance traveled in 1 hour at accepted cruise speed

which equates to:

$$S_{Total} = 24 + (4 \times 50) + 24 + (1 \times 50)$$

$$S_{Total} = 298nmi$$

1.2.4. Endurance_{C&MCZ}

The total endurance is calculated as follows:

- +Travel time at accepted cruise speed from coast to C&MCZ limit
- +Maximum Search Time
- +Travel time at accepted cruise speed from C&MCZ limit to coast
- +1 hour emergency time

which equates to:

$$T_{Total} = \left(\frac{24nmi}{50nmi/h} \right) + 4 + \left(\frac{24nmi}{50nmi/h} \right) + 1$$

$$T_{Total} = 5.96h$$

$$T_{Total} = 5h\ 58m$$

1.3. Search Location 3: Exclusive Economic Zone (EEZ)

The key performance requirements for assets operating to the limits of this location are calculated and deduced as follows:

1.3.1. Location Boundaries_{EEZ}

From Shoreline to 200nmi offshore.

1.3.2. Speed_{EEZ}

The minimum required cruise speed is calculated as follows:

$$V_{Cruise} = \frac{S_{EEZ}}{T_6}$$

$$V_{CruiseCalc} = \frac{200nmi}{6h}$$

$$V_{CruiseCalc} = 33.3nmi/h = 33.3kn$$

As explained in the sub-section for the Territorial Waters, the minimum required cruise speed is accepted as:

$$V_{CruiseAcc} = 50nmi / h = 50kn$$

I.3.3. Range_{EEZ}

The total range is calculated as follows:

- +Distance from coast to EEZ limit
- +Distance traveled in 4 hours at accepted cruise speed
- +Distance from EEZ limit to coast
- +Distance traveled in 1 hour at accepted cruise speed

which equates to:

$$S_{Total} = 200 + (4 \times 50) + 200 + (1 \times 50)$$

$$S_{Total} = 650nmi$$

I.3.4. Endurance_{EEZ}

The total endurance is calculated as follows:

- +Travel time at accepted cruise speed from coast to EEZ limit
- +Maximum Search Time
- +Travel time at accepted cruise speed from EEZ limit to coast
- +1 hour emergency time

which equates to:

$$T_{Total} = \left(\frac{200nmi}{50nmi / h} \right) + 4 + \left(\frac{200nmi}{50nmi / h} \right) + 1$$

$$T_{Total} = 13h$$

I.4. Search Location 4. Continental Shelf (CS)

The key performance requirements for assets operating to the limits of this location are calculated and deduced as follows:

1.4.1. Location Boundaries_{CS}

From Shoreline to 350nmi offshore.

1.4.2. Speed_{CS}

The minimum required cruise speed is calculated as follows:

$$V_{Cruise} = \frac{S_{CS}}{T_6}$$

$$V_{CruiseCalc} = \frac{350nmi}{6h}$$

$$V_{CruiseCalc} = 58.3nmi / h = 58.3kn$$

This value is greater than the 50kn minimum, and will therefore be retained for the other Continental Shelf location calculations.

1.4.3. Range_{CS}

The total range is calculated as follows:

- +Distance from coast to CS limit
- +Distance traveled in 4 hours at calculated cruise speed
- +Distance from CS limit to coast
- +Distance traveled in 1 hour at calculated cruise speed

which equates to:

$$S_{Total} = 350 + (4 \times 58.3) + 350 + (1 \times 58.3)$$

$$S_{Total} = 1166.4nmi$$

1.4.4. Endurance_{CS}

The total endurance is calculated as follows:

- +Travel time at calculated cruise speed from coast to CS limit
- +Maximum Search Time
- +Travel time at calculated cruise speed from CS limit to coast

+1 hour emergency time

which equates to:

$$T_{Total} = \left(\frac{350nmi}{58.3nmi/h} \right) + 4 + \left(\frac{350nmi}{58.3nmi/h} \right) + 1$$

$$T_{Total} = 6 + 4 + 6 + 1$$

$$T_{Total} = 17h$$

1.5. Search Location 5. Marion Island Rim (MIR)

The key performance requirements for assets operating to the limits of this location are calculated and deduced as follows:

1.5.1. Location Boundaries_{MIR}

From Shoreline to 1770nmi offshore.

1.5.2. Speed_{MIR}

The minimum required cruise speed is calculated as follows:

$$V_{Cruise} = \frac{S_{MIR}}{T_6}$$

$$V_{CruiseCalc} = \frac{1770nmi}{6h}$$

$$V_{CruiseCalc} = 295nmi/h = 295kn$$

This value is more than the 50kn minimum, and will therefore be retained for the other Marion Island Rim location calculations.

1.5.3. Range_{MIR}

The total range is calculated as follows:

- +Distance from coast to MIR limit
- +Distance traveled in 4 hours at calculated cruise speed
- +Distance from MIR limit to coast

+Distance traveled in 1 hour at calculated cruise speed

which equates to:

$$S_{Total} = 1770 + (4 \times 295) + 1770 + (1 \times 295)$$

$$S_{Total} = 4425 \text{ nmi}$$

1.5.4. Endurance_{MIR}

The total endurance is calculated as follows:

+Travel time at calculated cruise speed from coast to MIR limit

+Maximum Search Time

+Travel time at calculated cruise speed from MIR limit to coast

+1 hour emergency time

which equates to:

$$T_{Total} = \left(\frac{1770 \text{ nmi}}{295 \text{ nmi/h}} \right) + 4 + \left(\frac{1770 \text{ nmi}}{295 \text{ nmi/h}} \right) + 1$$

$$T_{Total} = 6 + 4 + 6 + 1$$

$$T_{Total} = 17 \text{ h}$$

1.6. Search Location 6. Search Extremities (SE)

The key performance requirements for assets operating to the limits of this location are calculated and deduced as follows:

1.6.1. Location Boundaries_{SE}

From Shoreline to 2800nmi offshore

1.6.2. Speed_{SE}

The minimum required cruise speed is calculated as follows:

$$V_{Cruise} = \frac{S_{SE}}{T_6}$$

$$V_{CruiseCalc} = \frac{2800nmi}{6h}$$

$$V_{CruiseCalc} = 466.7nmi / h = 466.7kn$$

This value is more than the 50kn minimum, and will therefore be retained for the other Search Extremities location calculations

1.6.3. Range_{SE}

The total range is calculated as follows:

- +Distance from coast to SE limit
- +Distance traveled in 4 hours at calculated cruise speed
- +Distance from SE limit to coast
- +Distance traveled in 1 hour at calculated cruise speed

which equates to:

$$S_{Total} = 2800 + (4 \times 466.7) + 2800 + (1 \times 466.7)$$

$$S_{Total} = 7933.5nmi$$

1.6.4. Endurance_{SE}

The total endurance is calculated as follows:

- +Travel time at calculated cruise speed from coast to SE limit
- +Maximum Search Time
- +Travel time at calculated cruise speed from SE limit to coast
- +1 hour emergency time

which equates to:

$$T_{Total} = \left(\frac{2800nmi}{466.7nmi / h} \right) + 4 + \left(\frac{2800nmi}{466.7nmi / h} \right) + 1$$

$$T_{Total} = 6 + 4 + 6 + 1$$

$$T_{Total} = 17h$$

Appendix J

J. Performance Shortcomings

Appendix J provides the detail analysis tables to determine the performance “deltas” per search location, for existing Search and Rescue aircraft.

J.1. Domestic SAR Aircraft

J.1.1. $Speed_{Dom}$

Table J.1 plots each domestic aircraft’s maximum cruise speed ($V_{CruiseMax}$) against the speed requirement for each of the six search locations.

Aircraft Type _{Domestic}	$V_{CruiseMax}$	TW 50	C&MCZ 50	EEZ 50	CS 58.3	MIR 295	SE 466.7
Agusta Westland A109 LUH	153						
Agusta Westland A109E Power	154						
Agusta Westland A109S Grand	156						
Beech King Air 200/B200C	289.4						
Beech King Air 300	315.4						
Bell 212 Twin Huey	100						
CASA 212-200/300	180						
CASA CN-235 (prototype)	230						
Cessna C208A Caravan	175						
Convair 580	280						
Denel Oryx M1/M2	120						
Douglas C47-TP MP&NT	160						
Eurocopter AS 350 B3	140						
Eurocopter EC 120B Colibri	120						
Kamov Ka-32A	118.8						
Lockheed C-130BZ Hercules	300						
MBB BO105 CBS-5	134						
MBB/Kawasaki BK117	133.8						
MD Helicopters MD-500E LEH	170						
Mil Mi-8 MTV	116						
Mil Mi-8 P	116						
Pilatus PC-6 Porter	125						
Pilatus PC-12	280						
Robinson R44 Raven II	117						
Sikorsky S-61N MkII	114.4						
Sikorsky S-76A++ Spirit	137						
Westland Super Lynx 300	132						

Table J.1: Maximum Cruise Speed vs Search Location Requirement (Domestic Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required cruise speed. Red shaded cells indicate the converse. All speeds are in knots.

J.1.2. $Range_{Dom}$

Table J.2 plots each domestic aircraft’s maximum range (S_{Max}) against the range requirement for each of the six search locations.

Aircraft Type_{Domestic}	S_{Max}	TW 274	C&MCZ 298	EEZ 650	CS 1166.4	MIR 4425	SE 7933.5
Agusta Westland A109 LUH	500						
Agusta Westland A109E Power	512						
Agusta Westland A109S Grand	424						
Beech King Air 200/B200C	1974.3						
Beech King Air 300	1960.4						
Bell 212 Twin Huey	236.4						
CASA 212-200/300	800						
CASA CN-235 (prototype)	2000						
Cessna C208A Caravan	869						
Convair 580	1200						
Denel Oryx M1/M2	827						
Douglas C47-TP MP&NT	1300						
Eurocopter AS 350 B3	359						
Eurocopter EC 120B Colibri	383						
Kamov Ka-32A	475						
Lockheed C-130BZ Hercules	2699.8						
MBB BO105 CBS-5	600						
MBB/Kawasaki BK117	307.6						
MD Helicopters MD-500E LEH	287						
Mil Mi-8 MTV	567						
Mil Mi-8 P	737						
Pilatus PC-6 Porter	500						
Pilatus PC-12	1560						
Robinson R44 Raven II	304.1						
Sikorsky S-61N MkII	400.6						
Sikorsky S-76A++ Spirit	411						
Westland Super Lynx 300	280						

Table J.2 Maximum Range vs Search Location Requirement (Domestic Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required range. Red shaded cells indicate the converse. All ranges are in nautical miles.

J.1.3. Endurance_{Dom}

Table J.3 plots each domestic aircraft's maximum endurance (T_{Max}) against the endurance requirement for each of the six search locations.

Aircraft Type_{Domestic}	T_{Max}	TW 5h28m	C&MCZ 5h58m	EEZ 13	CS 17	MIR 17	SE 17
Agusta Westland A109 LUH	3h16m						
Agusta Westland A109E Power	3h19m						
Agusta Westland A109S Grand	2h43m						
Beech King Air 200/B200C	6h49m						
Beech King Air 300	6h12m						
Bell 212 Twin Huey	2h21m						
CASA 212-200/300	4h26m						
CASA CN-235 (prototype)	8h42m						
Cessna C208A Caravan	5h						
Convair 580	4h17m						
Denel Oryx M1/M2	6h53m						
Douglas C47-TP MP&NT	8h7m						
Eurocopter AS 350 B3	2h33m						
Eurocopter EC 120B Colibri	3h11m						
Kamov Ka-32A	4h						
Lockheed C-130BZ Hercules	9h						
MBB BO105 CBS-5	4h28m						
MBB/Kawasaki BK117	2h17m						
MD Helicopters MD-500E LEH	1h41m						
Mil Mi-8 MTV	4h53m						
Mil Mi-8 P	6h21m						
Pilatus PC-6 Porter	4h						
Pilatus PC-12	5h34m						
Robinson R44 Raven II	2h35m						
Sikorsky S-61N MkII	3h30m						
Sikorsky S-76A++ Spirit	3h						
Westland Super Lynx 300	2h7m						

Table J.3: Maximum Endurance vs Search Location Requirement (Domestic Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required endurance. Red shaded cells indicate the converse. All endurance figures are in hours and minutes.

J.1.4. Combined Effects Table_{Dom}

Table J.4 plots each domestic aircraft's maximum speed, range and endurance in combined effect against each of the six search locations and their requirements. A red cell in any of the three tables above merits a red cell in the combined effects table.

Aircraft Type _{Domestic}	TW	C&MCZ	EEZ	CS	MIR	SE
Agusta Westland A109 LUH						
Agusta Westland A109E Power						
Agusta Westland A109S Grand						
Beech King Air 200/B200C						
Beech King Air 300						
Bell 212 Twin Huey						
CASA 212-200/300						
CASA CN-235 (prototype)						
Cessna C208A Caravan						
Convair 580						
Denel Oryx M1/M2						
Douglas C47-TP MP&NT						
Eurocopter AS 350 B3						
Eurocopter EC 120B Colibri						
Kamov Ka-32A						
Lockheed C-130BZ Hercules						
MBB BO105 CBS-5						
MBB/Kawasaki BK117						
MD Helicopters MD-500E LEH						
Mil Mi-8 MTV						
Mil Mi-8 P						
Pilatus PC-6 Porter						
Pilatus PC-12						
Robinson R44 Raven II						
Sikorsky S-61N MkII						
Sikorsky S-76A++ Spirit						
Westland Super Lynx 300						

Table J.4: Combined Performance Effects vs Search Location Requirements (Domestic Aircraft)

From Table J.4 it is evident that only 30% of the available domestic aircraft types, currently deployable for maritime Search and Rescue, are capable of meeting all key performance requirements, and this for primarily the TW and C&MCZ search locations.

This leaves a very large shortcoming in terms of airborne maritime Search and Rescue, particularly for situations involving incidents beyond the 24nmi C&MCZ.

J.2. Foreign SAR Aircraft

J.2.1. $Speed_{For}$

Table J.5 plots each foreign aircraft's maximum cruise speed ($V_{CruiseMax}$) against the speed requirement for each of the six search locations.

Aircraft Type _{Foreign}	V _{CruiseMax}	TW 50	C&MCZ 50	EEZ 50	CS 58.3	MIR 295	SE 466.7
Agusta Westland AW139	165						
Agusta Westland Merlin HM1	136						
Alenia/ATR 42 MP Surveyor	190						
Alenia/ATR 72 ASW	145						
Alenia C27J Spartan	325						
BAe Nimrod MRA4	442.8						
Bell 214 ST	140						
Bell 407	118						
Bell 412 EP	131						
Bell 427	133						
Bell 429	142						
Bell/Agusta BA 609	275						
Bell/Boeing MV-22B Osprey	250						
Bell UH-1Y Venom	135						
Boeing P-8A Poseidon	490						
Bombardier/DHC Dash 8 Q200	290						
Bombardier/DHC Dash 8 Q400	361						
CASA CN-235MP Persuader	130						
CASA C-295 Persuader	145						
Dassault Atlantique ATL2	299.8						
Dassault Falcon 900 MPA	496.1						
Embraer P-99 (EMB 145 MP)	444.1						
Eurocopter AS 332 L2 Super Puma	150						
Eurocopter AS 365 N3 Dauphin	145						
Eurocopter AS 532 SC Cougar	136						
Eurocopter AS 555 Fennec	118						
Eurocopter AS 565 Panther	145						
Eurocopter EC 225 Super Puma	141.5						
Eurocopter EC 725 Cougar	141						
Eurocopter MH-65C Dolphin	165						
Fairchild-Dornier Do-228-101 MPA	165.1						
Fokker 50 Maritime	150						
Ilyushin Il-38 May	348.5						
Kaman SH-2G Super Seasprite	120						
Lockheed HC-130J Hercules	339						
Lockheed P-3C Orion	328						
Lockheed CP-140 Aurora							
MD Helicopters MD-600N	115						
NH Industries NH90 FSH/NFH	132						
Reims-Cessna F406	246						
Shaanxi Y-8X MPA	350						
Sikorsky CH-148 Cyclone (MH-92)	137						
Sikorsky CH-53E Super Stallion	150.1						
Sikorsky MH-53E Sea Dragon	150						
Sikorsky MH-60T Jayhawk	170						
Sikorsky S-70B Sea Hawk	146						
Tupolev Tu-142M Bear-F	500						

Table J.5: Maximum Cruise Speed vs Search Location Requirement (Foreign Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required cruise speed. Red shaded cells indicate the converse. All speeds are in knots.

J.2.2. Range_{For}

Table J.6 plots each foreign aircraft's maximum range (S_{Max}) against the range requirement for each of the six search locations.

Aircraft Type _{Foreign}	S _{Max}	TW 274	C&MCZ 298	EEZ 650	CS 1166.4	MIR 4425	SE 7933.5
Agusta Westland AW139	573						
Agusta Westland Merlin HM1	900						
Alenia/ATR 42 MP Surveyor	2020						
Alenia/ATR 72 ASW	1505						
Alenia C27J Spartan	3200						
BAe Nimrod MRA4	6000						
Bell 214 ST	435.4						
Bell 407	383						
Bell 412 EP	423						
Bell 427	400						
Bell 429	350						
Bell/Agusta BA 609	700						
Bell/Boeing MV-22B Osprey	1800						
Bell UH-1Y Venom	260						
Boeing P-8A Poseidon	3160						
Bombardier/DHC Dash 8 Q200	973						
Bombardier/DHC Dash 8 Q400	1526						
CASA CN-235MP Persuader	2300						
CASA C-295 Persuader	2400						
Dassault Atlantique ATL2	4900.2						
Dassault Falcon 900 MPA	4100						
Embraer P-99 (EMB 145 MP)	2050						
Eurocopter AS 332 L2 Super Puma	446						
Eurocopter AS 365 N3 Dauphin	427						
Eurocopter AS 532 SC Cougar	492						
Eurocopter AS 555 Fennec	375						
Eurocopter AS 565 Panther	427						
Eurocopter EC 225 Super Puma	506						
Eurocopter EC 725 Cougar	692						
Eurocopter MH-65C Dolphin	300						
Fairchild-Dornier Do-228-101 MPA	1722.3						
Fokker 50 Maritime	2340						
Ilyushin Il-38 May	4049.4						
Kaman SH-2G Super Seasprite	540						
Lockheed HC-130J Hercules	5500						
Lockheed P-3C Orion	4760						
Lockheed CP-140 Aurora							
MD Helicopters MD-600N	423						
NH Industries NH90 FSH/NFH	659						
Reims-Cessna F406	1200						
Shaanxi Y-8X MPA	4211						
Sikorsky CH-148 Cyclone (MH-92)	525						
Sikorsky CH-53E Super Stallion	1119.9						
Sikorsky MH-53E Sea Dragon	1050						
Sikorsky MH-60T Jayhawk	300						
Sikorsky S-70B Sea Hawk	450						
Tupolev Tu-142M Bear-F	6775						

Table J.6: Maximum Range vs Search Location Requirement (Foreign Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required range. Red shaded cells indicate the converse. All ranges are in nautical miles.

J.2.3 Endurance_{For}

Table J.7 plots each foreign aircraft's maximum endurance (T_{Max}) against the endurance requirement for each of the six search locations.

Aircraft Type_{Foreign}	T_{Max}	TW 5h28m	C&MCZ 5h58m	EEZ 13	CS 17	MIR 17	SE 17
Agusta Westland AW139	3h28m						
Agusta Westland Merlin HM1	6h37m						
Alenia/ATR 42 MP Surveyor	10h37m						
Alenia/ATR 72 ASW	10h22m						
Alenia C27J Spartan	9h50m						
BAe Nimrod MRA4	13h33m						
Bell 214 ST	3h6m						
Bell 407	3h14m						
Bell 412 EP	3h13m						
Bell 427	3h						
Bell 429	2h27m						
Bell/Agusta BA 609	2h32m						
Bell/Boeing MV-22B Osprey	7h12m						
Bell UH-1Y Venom	1h55m						
Boeing P-8A Poseidon	6h26m						
Bombardier/DHC Dash 8 Q200	3h21m						
Bombardier/DHC Dash 8 Q400	4h13m						
CASA CN-235MP Persuader	17h41m						
CASA C-295 Persuader	16h33m						
Dassault Atlantique ATL2	16h20m						
Dassault Falcon 900 MPA	8h15m						
Embraer P-99 (EMB 145 MP)	4h36m						
Eurocopter AS 332 L2 Super Puma	3h						
Eurocopter AS 365 N3 Dauphin	3h						
Eurocopter AS 532 SC Cougar	3h37m						
Eurocopter AS 555 Fennec	3h10m						
Eurocopter AS 565 Panther	3h						
Eurocopter EC 225 Super Puma	3h34m						
Eurocopter EC 725 Cougar	4h54m						
Eurocopter MH-65C Dolphin	1h49m						
Fairchild-Dornier Do-228-101 MPA	10h25m						
Fokker 50 Maritime	15h36m						
Ilyushin Il-38 May	11h37m						
Kaman SH-2G Super Seasprite	4h30m						
Lockheed HC-130J Hercules	16h13m						
Lockheed P-3C Orion	14h30m						
Lockheed CP-140 Aurora							
MD Helicopters MD-600N	3h40m						
NH Industries NH90 FSH/NFH	5h						
Reims-Cessna F406	4h52m						
Shaanxi Y-8X MPA	12h1m						
Sikorsky CH-148 Cyclone (MH-92)	3h49m						
Sikorsky CH-53E Super Stallion	7h27m						
Sikorsky MH-53E Sea Dragon	7h						
Sikorsky MH-60T Jayhawk	1h45m						
Sikorsky S-70B Sea Hawk	3h4m						
Tupolev Tu-142M Bear-F	13h33m						

Table J.7: Maximum Endurance vs Search Location Requirement (Foreign Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required endurance. Red shaded cells indicate the converse. All endurance figures are in hours and minutes.

J.2.4. Combined Effects Table_{For}

Table J.8 plots each foreign aircraft's maximum speed, range and endurance in combined effect against each of the six search locations and their requirements. A red cell in any of the three tables above merits a red cell in the combined effects table.

Aircraft Type ^{Foreign}	TW	C&MCZ	EEZ	CS	MIR	SE
Agusta Westland AW139						
Agusta Westland Merlin HM1						
Alenia/ATR 42 MP Surveyor						
Alenia/ATR 72 ASW						
Alenia C27J Spartan						
BAe Nimrod MRA4						
Bell 214 ST						
Bell 407						
Bell 412 EP						
Bell 427						
Bell 429						
Bell/Agusta BA 609						
Bell/Boeing MV-22B Osprey						
Bell UH-1Y Venom						
Boeing P-8A Poseidon						
Bombardier/DHC Dash 8 Q200						
Bombardier/DHC Dash 8 Q400						
CASA CN-235MP Persuader						
CASA C-295 Persuader						
Dassault Atlantique ATL2						
Dassault Falcon 900 MPA						
Embraer P-99 (EMB 145 MP)						
Eurocopter AS 332 L2 Super Puma						
Eurocopter AS 365 N3 Dauphin						
Eurocopter AS 532 SC Cougar						
Eurocopter AS 555 Fennec						
Eurocopter AS 565 Panther						
Eurocopter EC 225 Super Puma						
Eurocopter EC 725 Cougar						
Eurocopter MH-65C Dolphin						
Fairchild-Dornier Do-228-101 MPA						
Fokker 50 Maritime						
Ilyushin Il-38 May						
Kaman SH-2G Super Seasprite						
Lockheed HC-130J Hercules						
Lockheed P-3C Orion						
Lockheed CP-140 Aurora						
MD Helicopters MD-600N						
NH Industries NH90 FSH/NFH						
Reims-Cessna F406						
Shaanxi Y-8X MPA						
Sikorsky CH-148 Cyclone (MH-92)						
Sikorsky CH-53E Super Stallion						
Sikorsky MH-53E Sea Dragon						
Sikorsky MH-60T Jayhawk						
Sikorsky S-70B Sea Hawk						
Tupolev Tu-142M Bear-F						

Table J.8: Combined Performance Effects vs Search Location Requirements (Foreign Aircraft)

From Table J.8 it is evident that only about 40% of the available foreign aircraft types, currently deployable for maritime Search and Rescue, are capable of meeting all key performance requirements, and this for primarily the TW and C&MCZ search locations. Only 8 types are capable of meeting all key performance requirements within the EEZ, and only one type within the CS.

This leaves a very large shortcoming in terms of airborne maritime Search and Rescue, particularly for situations involving incidents beyond the 200nm EEZ.

J.3. Unmanned SAR Assets

J.3.1. $Speed_{UAV}$

Table J.9 plots each unmanned aircraft's maximum cruise speed ($V_{CruiseMax}$) against the speed requirement for each of the six search locations.

Aircraft Type _{Unmanned}	$V_{CruiseMax}$	TW 50	C&MCZ 50	EEZ 50	CS 58.3	MIR 295	SE 466.7
AAI RQ-7B Shadow 200	90	Green	Green	Green	Green	Red	Red
BAe HERTI	90	Green	Green	Green	Green	Red	Red
Bell TR916 Eagle Eye	200	Green	Green	Green	Green	Red	Red
Boeing A160T Hummingbird	112.5	Green	Green	Green	Green	Red	Red
Denel Dynamics Bateleur	135	Green	Green	Green	Green	Red	Red
EADS ORKA-1200	105.3	Green	Green	Green	Green	Red	Red
Elbit Hermes 450	70	Green	Green	Green	Green	Red	Red
Elbit Hermes 1500	80	Green	Green	Green	Green	Red	Red
General Atomics RQ-1/MQ-1 Predator	120	Green	Green	Green	Green	Red	Red
General Atomics MQ-9 Reaper	240	Green	Green	Green	Green	Red	Red
General Atomics Mariner	157	Green	Green	Green	Green	Red	Red
IAI Heron TP (Eitan)	200	Green	Green	Green	Green	Red	Red
IAI/EADS Eagle 1/Heron 1/Harfang	80	Green	Green	Green	Green	Red	Red
IAI/EADS Eagle 2	180	Green	Green	Green	Green	Red	Red
IAI/PUI RQ-2 Pioneer	110	Green	Green	Green	Green	Red	Red
InSitu/Boeing ScanEagle	49	Red	Red	Red	Red	Red	Red
Northrop Grumman MQ-8B Fire Scout	110	Green	Green	Green	Green	Red	Red
Northrop Grumman RQ-4A Global Hawk	343	Green	Green	Green	Green	Green	Red
RUAG Ranger	70	Green	Green	Green	Green	Red	Red
SAAB Skeldar V-200	70	Green	Green	Green	Green	Red	Red
Sagem Sperwer B	81	Green	Green	Green	Green	Red	Red
Schiebel Camcopter	55	Green	Green	Green	Red	Red	Red
Swift Killer Bee	64.8	Green	Green	Green	Green	Red	Red
Warrior/Aero-Marine Gull 68	100	Green	Green	Green	Green	Red	Red

Table J.9: Maximum Cruise Speed vs Search Location Requirement (Unmanned Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required cruise speed. Red shaded cells indicate the converse. All speeds are in knots.

J.3.2. $Range (Communications)_{UAV}$

Table J-10 plots each unmanned aircraft's maximum communications range ($S_{CommsMax}$) against the range requirement for each of the six search locations.

Aircraft Type _{Unmanned}	S_{CommsMax}	TW 274	C&MCZ 298	EEZ 650	CS 1166.4	MIR 4425	SE 7933.5
AAI RQ-7B Shadow 200	68						
BAe HERTI	Range max						
Bell TR916 Eagle Eye	100						
Boeing A160T Hummingbird	110						
Denel Dynamics Bateleur	Satcom						
EADS ORKA-1200	Tactical 110						
Elbit Hermes 450	108 (std)						
Elbit Hermes 1500	108 (std)						
General Atomics RQ-1/MQ-1 Predator	Satcom						
General Atomics MQ-9 Reaper	Satcom						
General Atomics Mariner	Satcom						
IAI Heron TP (Eitan)	Satcom						
IAI/EADS Eagle 1/Heron 1/Harfang	Satcom						
IAI/EADS Eagle 2	Satcom						
IAI/PUI RQ-2 Pioneer	100						
InSitu/Boeing ScanEagle	Range max						
Northrop Grumman MQ-8B Fire Scout	110						
Northrop Grumman RQ-4A Global Hawk	Satcom						
RUAG Ranger	97						
SAAB Skeldar V-200	81						
Sagem Sperwer B	108						
Schiebel Camcopter	97						
Swift Killer Bee	50						
Warrior/Aero-Marine Gull 68	100						

Table J.10: Maximum Communications Range vs Search Location Requirement (Unmanned Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required range. Red shaded cells indicate the converse. All ranges are in nautical miles.

J.3.3. *Range*_{UAV}

Table J.11 plots each unmanned aircraft's maximum range (S_{Max}) against the range requirement for each of the six search locations.

Aircraft Type _{Unmanned}	S _{Max}	TW 274	C&MCZ 298	EEZ 650	CS 1166.4	MIR 4425	SE 7933.5
AAI RQ-7B Shadow 200	540						
BAe HERTI	2250						
Bell TR916 Eagle Eye	800						
Boeing A160T Hummingbird	2250						
Denel Dynamics Bateleur	2430						
EADS ORKA-1200	842						
Elbit Hermes 450	1400						
Elbit Hermes 1500	2080						
General Atomics RQ-1/MQ-1 Predator	4800						
General Atomics MQ-9 Reaper	7200						
General Atomics Mariner	7100						
IAI Heron TP (Eitan)	7200						
IAI/EADS Eagle 1/Heron 1/Harfang	2400						
IAI/EADS Eagle 2	4320						
IAI/PUI RQ-2 Pioneer	495						
InSitu/Boeing ScanEagle	980						
Northrop Grumman MQ-8B Fire Scout	880						
Northrop Grumman RQ-4A Global Hawk	12000						
RUAG Ranger	630						
SAAB Skeldar V-200	350						
Sagem Sperwer B	972						
Schiebel Camcopter	330						
Swift Killer Bee	972						
Warrior/Aero-Marine Gull 68	1124						

Table J.11: Maximum Range vs Search Location Requirement (Unmanned Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required range. Red shaded cells indicate the converse. All ranges are in nautical miles.

J.3.4. Endurance_{UAV}

Table J.12 plots each unmanned aircraft's maximum endurance (T_{Max}) against the endurance requirement for each of the six search locations.

Aircraft Type _{Unmanned}	T_{Max}	TW 5h28m	C&MCZ 5h58m	EEZ 13	CS 17	MIR 17	SE 17
AAI RQ-7B Shadow 200	6h						
BAe HERTI	25h						
Bell TR916 Eagle Eye	4h						
Boeing A160T Hummingbird	20h						
Denel Dynamics Bateleur	18h						
EADS ORKA-1200	8h						
Elbit Hermes 450	20h						
Elbit Hermes 1500	26h						
General Atomics RQ-1/MQ-1 Predator	40h						
General Atomics MQ-9 Reaper	30h						
General Atomics Mariner	45h13m						
IAI Heron TP (Eitan)	36h						
IAI/EADS Eagle 1/Heron 1/Harfang	30h						
IAI/EADS Eagle 2	24h						
IAI/PUI RQ-2 Pioneer	4h30m						
InSitu/Boeing ScanEagle	20h						
Northrop Grumman MQ-8B Fire Scout	8h						
Northrop Grumman RQ-4A Global Hawk	35h						
RUAG Ranger	9h						
SAAB Skeldar V-200	5h						
Sagem Sperwer B	12h						
Schiebel Camcopter	6h						
Swift Killer Bee	15h						
Warrior/Aero-Marine Gull 68	11h14m						

Table J.12: Maximum Endurance vs Search Location Requirement (Unmanned Aircraft)

Green shaded cells indicate the search locations where existing aircraft are capable of reaching the required endurance. Red shaded cells indicate the converse. All endurance figures are in hours and minutes.

J.3.5. Combined Effects Table_{UAV}

Table J.13 plots each unmanned aircraft's maximum cruise speed, communications range, range and endurance in combined effect against each of the six search locations and their requirements. A red cell in any of the four tables above merits a red cell in the combined effects table.

Aircraft Type ^{Unmanned}	TW	C&MCZ	EEZ	CS	MIR	SE
AAI RQ-7B Shadow 200						
BAe HERTI						
Bell TR916 Eagle Eye						
Boeing A160T Hummingbird						
Denel Dynamics Bateleur						
EADS ORKA-1200						
Elbit Hermes 450						
Elbit Hermes 1500						
General Atomics RQ-1/MQ-1 Predator						
General Atomics MQ-9 Reaper						
General Atomics Mariner						
IAI Heron TP (Eitan)						
IAI/EADS Eagle 1/Heron 1/Harfang						
IAI/EADS Eagle 2						
IAI/PUI RQ-2 Pioneer						
InSitu/Boeing ScanEagle						
Northrop Grumman MQ-8B Fire Scout						
Northrop Grumman RQ-4A Global Hawk						
RUAG Ranger						
SAAB Skeldar V-200						
Sagem Sperwer B						
Schiebel Camcopter						
Swift Killer Bee						
Warrior/Aero-Marine Gull 68						

Table J.13: Combined Performance Effects vs Search Location Requirements (Unmanned Aircraft)

From Table J.13 it is evident that only about 37% of the available unmanned aircraft types, currently deployable for maritime Search and Rescue, are capable of meeting all key performance requirements, and this for primarily the TW, C&MCZ, EEZ and CS search locations. Only one type is capable of meeting all performance requirements for the MIR.

This leaves a large shortcoming in terms of airborne maritime Search and Rescue, particularly for situations involving incidents beyond the 350nmi CS.

PART 2

Appendices

Appendix K

K. Unmanned Aircraft Design Analysis: A. Maneschijn

Appendix K provides the detail analysis for the concept design of the Unmanned Aircraft, as presented in the book by Mr A. Maneschijn, entitled “An Introduction to Experimental Light Aircraft Design”^[109].

K.1. Method 1: Experimental Light Aircraft Design, 1st Edition^[109]

The first method for determining the conceptual design for the UA centered primarily on concepts for the design of experimental light aircraft, as contained in the reference material by Mr A. Maneschijn^[109]. Although this design is not strictly for a light aircraft, it is largely “conventional”, and as such the principles and approach remain largely coherent with that provided in the reference material. Where assumptions were made, it has been clearly stated, with logical deductions.

The actual calculations were performed in Excel. Results are summarized in Chapter 14.

K.1.1. Performance Prediction

The first calculation set focuses on the performance prediction for the UA.

K.1.1.1. Maximum All-Up (Take-off) Weight

Initial performance predictions involve the estimation of maximum all-up weight, maximum fuel weight and payload weight. In order to start somewhere, an existing manned aircraft was sought having similar performance as the three key performance requirements determined for this study. As it has already been shown, currently no single aircraft employed in the maritime search and rescue role exhibits all three key performance characteristics. However, a few aircraft utilized for other functions do come close. The Gulfstream G550 was selected as a comparative platform to aide with initial sizing and weights. The key performance requirements for this design compares with those of the G550 as follows:

Aircraft Type	V _{Max Cruise} (kn)	S _{Max} (nmi)	T _{Max} (h)
Design Requirement	466.7	7,933.5	17
Gulfstream G550	459	6,750	14.7
Difference	7.7	1,183.5	2.3
% Difference	1.68%	17.53%	15.66%

Table K.1: G550 Performance Comparison

The differences in speed are negligibly small. The primary difference lies with range and endurance, an average 17% higher requirement for this design over the G550. All things being equal, including speed, the primary design trait providing the increase in range and endurance should a greater fuel load, which should influence the maximum all-up weight.

The maximum all-up weight for the G550 is 41,277 kg. A 16% increase in this weight takes it up to 47,881 kg. The UA for this design is unmanned, eliminating the cockpit and cabin from the weight equation. Therefore, as an initial estimate, a maximum all-up weight of 45,000 kg is adopted for this design.

Before calculating the maximum fuel weight, a number of other parameters will be calculated. Some of these parameters are required for the calculation of maximum fuel weight.

K.1.1.2. Stall Speeds

The stall speeds will be calculated at two altitudes: sea level and cruise altitude of 40,000 ft. The air density differs substantially at these altitudes, and is as follows:

- Air density at sea level: $\rho_{\text{sea}} = 1.225 \text{ kg/m}^3$
- Air density at 40,000 ft: $\rho_{\text{alt}} = 0.244 \times \rho_{\text{sea}} = 0.299 \text{ kg/m}^3$

The following speeds will be determined in this sub-section:

- V_{stallSea} , the stall speed at sea level
- V_{stallAlt} , the stall speed at cruising altitude

A critical element in the calculation of many following values is the wing area. To calculate this value, we first estimate the stall speed at sea level to be 112 knots (207.424 km/h; 57.62 m/s). The wing area is calculated form:

$$S_{wing} = \frac{W \times g}{0.5 \times \rho_{sea} \times C_{lmax} \times V_{stallSea}^2}, \text{ where}$$

- W is the maximum all-up weight
- C_{lmax} is the maximum lift coefficient, and typically ranges as follows:
 - 1.0 to 1.5 for an un-flapped wing
 - 1.8 to 3.0 for a flapped wing

For this design, C_{lmax} is estimated to be 2.0.

Therefore, the wing area for this design is:

$$S_{wing} = \frac{45,000 * 9.81}{0.5 * 1.225 * 2 * 57.62^2}$$

- S_{wing} is 108.55 m², which checks well with the G550, which has a wing area of 106 m².

Stall speed at cruising altitude is calculated by rearranging the wing area formula into:

$$V_{stallAlt} = \sqrt{\frac{(W \times g) \div S_{wing}}{0.5 \times \rho_{alt} \times C_{lmax}}}$$

Therefore, the stall speed at cruising altitude for this design is:

$$V_{stallAlt} = \sqrt{\frac{(45,000 * 9.81) / 108.55}{0.5 * 0.299 * 2}}$$

- $V_{stallAlt}$ is 116.64 m/s (419.92 km/h; 226.74 kn)

K.1.1.3. Basic Dimensions

The following basic dimensions will be determined in this sub-section:

- L, the total length of the fuselage
- AR_{wing} , the wing aspect ratio
- b_{wing} , the wing span
- c_{aWing} , the average chord of the wing
- c_{rWing} , the root chord of the wing
- c_{tWing} , the tip chord of the wing

The length of the fuselage is initially chosen as 22 m, based on the G550.

The aspect ratio of the wing is the ratio of the wing span to the average chord; the greater the span, the greater the ratio. High aspect ratios (6 to 10) deliver lower cruising speeds, higher rates of climb and greater endurance. Lower aspect ratios (4 to 6) deliver faster cruising speeds, lower rates of climb and lower endurance. This design requires a high sub-sonic cruising speed with very long endurance. An aspect ratio of 7 is chosen, matching well to that of the similarly-performing G550.

The wing span can be estimated from:

$$b_{wing} = \sqrt{AR_{wing} \times S_{wing}}$$

Therefore, the wing span is:

$$b_{wing} = \sqrt{7 * 108.55}$$

- b_{wing} is 27.57 m, which correlates well with the 28.5 m wing span of the G550.

The average wing chord can be estimated from:

$$C_{aWing} = \frac{S_{wing}}{n \times b_{wing}}, \text{ where}$$

- n is the number of wings

Therefore, the average wing chord is:

$$C_{aWing} = \frac{108.55}{1 \times 27.57}$$

- C_{aWing} is 3.94 m

The wing root and tip chords can be determined from the average chord. The wing root chord is selected to be 5.5 m. The wing tip chord is then calculated from:

$$C_{aWing} = \frac{C_{rWing} + C_{tWing}}{2}$$

Therefore, the wing tip chord is:

$$C_{tWing} = (3.94 \times 2) - 5.5$$

- C_{tWing} is 2.38 m

The fuselage and nose width and height are required as input for estimation of drag, which is required as input for the verification of the key performance requirements. Determination of fuselage diameters for unmanned aircraft differs from manned aircraft primarily in the sense that manned aircraft require larger diameters to accommodate passengers. The reference material used^[109] provides guidelines for the development of manned light aircraft, and the Gulfstream G550 used as a reference is also a manned, passenger-carrying VIP aircraft. These figures are therefore randomly selected, based on estimated capacity for fuel, equipment and payload to be accommodated inside the fuselage:

- b_{fuse} is 2 m

- h_{fuse} is 2.5 m
- b_{nose} is 2 m
- h_{nose} is 2.5 m

The values are rough and conservative estimates, and deliver a fuselage of good proportions, capable of supporting the wing, equipment and internal fuel.

K.1.1.4. Aerodynamic Drag

This sub-section calculates the drag as a result of aerodynamic forces acting on various key portions of the UA. The procedure described in the reference material for this Chapter is used, and, although it does not include all forms of drag (e.g. it excludes parasitic drag), the estimation is sufficient for the purposes of this concept design.

The zero lift drag coefficient is calculated from:

$$C_{d0} = \frac{r_{\text{Re}} \times r_{\text{uc}} \times \{r_t \times [(C_d S)_w + (C_d S)_f] + (C_d S)_n\}}{S_{\text{wing}}}, \text{ where}$$

- r_{Re} is the airflow correction factor, assumed to be 1.65
- r_{uc} is the drag due to undercarriage, taken as 1.0 for fully retractable undercarriage
- r_t is the drag due the empennage, taken as 1.24 for conventional tailplane configurations
- $(C_d S)_w$ is the drag due to the wing
- $(C_d S)_f$ is the drag due to the fuselage
- $(C_d S)_n$ is the drag due to the cowling, or the nose in this instance

The drag due to the wing is calculated from:

$$(C_d S)_w = 0.0054 \times r_w \times S_{\text{wing}}, \text{ where}$$

- r_w is 1.0 for a cantilever wing, 1.1 for a strut-braced design, and 1.2 for a biplane with struts and wires

Therefore, drag due to the wing is:

$$(C_d S)_w = 0.0054 * 1 * 108.55$$

- $(C_d S)_w$ is 0.586

The drag due to the fuselage is calculated from:

$$(C_d S)_f = 0.0031 \times r_f \times L \times (b_{fuse} + h_{fuse}), \text{ where}$$

- r_f is 1.0 for a circular fuselage cross-section, 1.15 for a semi-circular or semi-rectangular fuselage cross-section, and 1.3 for a rectangular fuselage cross-section

Therefore, drag due to the fuselage is:

$$(C_d S)_f = 0.0031 * 1.15 * 22 * (2 + 2.5)$$

- $(C_d S)_f$ is 0.353

The drag due to the nose is calculated from:

$$(C_d S)_n = 0.015 \times b_{nose} \times h_{nose} \times n, \text{ where}$$

- n is the number of engines

Therefore, drag due to the nose is:

$$(C_d S)_n = 0.015 * 2 * 2.5 * 2$$

- $(C_d S)_n$ is 0.15

The zero lift drag coefficient is therefore calculated as:

$$C_{d0} = \frac{1.65 * 1 * \{(1.24 * [0.586 + 0.353]) + 0.15\}}{108.55}$$

- C_{d0} is 0.02

This value will be used to help calculate amongst others the maximum- and cruising speeds, at sea level and cruising altitude.

K.1.1.5. Maximum and Cruising Speeds

This sub-section determines the following speeds:

- $V_{\max\text{Sea}100}$, the maximum speed at sea level, at 100% engine power
- $V_{\max\text{Alt}100}$, the maximum speed at cruising altitude, at 100% engine power
- $V_{\text{cruiseSea}85}$, the cruise speed at sea level, at 85% engine power
- $V_{\text{cruiseAlt}85}$, the cruise speed at cruising altitude, at 85% engine power

As for the stall speed, maximum and cruise speeds will be calculated at sea level and cruising altitude.

Both maximum and cruise speeds are calculated using the following equation:

$$V = \sqrt{\frac{2 \times \eta_p \times P \times f}{\rho \times C_{d0} \times S_{\text{wing}}}}, \text{ where}$$

- η_p is the overall propulsive efficiency
- P is the engine power (thrust in Newton, for this design)
- f is the fraction of power selected – 1 (100% engine power) for maximum speeds; 0.85 (85% engine power) for cruise speeds

Propulsive efficiency of turbine engines increases as altitude increases. The reference work “Synthesis of Subsonic Airplane Design” by Egbert Torenbeek, p 114, contains a graph indicating the propulsive efficiency for various types of turbine engines at various Mach numbers. This indicates that at around Mach 0.8, which is the cruise speed at cruising altitude for the equivalent G550, the efficiency for a bypass turbofan is around 60%, while at Mach 0.3 (near stall

speed at sea level) the efficiency is around 35%. Therefore, the following propulsive efficiencies are adopted for this concept design:

- η_{pSea} is 0.35
- η_{pAlt} is 0.6

The engine of choice, the BMW/Rolls-Royce BR710, delivers a maximum of 14,750 lbf of thrust at sea level. This design incorporates two engines, therefore maximum thrust at sea level is 29,500 lbf (131,220 N). The reference work “A Preliminary Design Proposal for a maritime Strike Aircraft”, University of Kansas, p 74, contains a graph indicating variation of engine thrust at various Mach numbers and altitudes. At cruising altitude of 40,000 ft, the available engine power is around one quarter of full available engine power at sea level. For this study, the available engine power at cruising altitude is estimated at 3,540 lbf per engine, or 7,080 lbf (31,500 N) total.

The maximum speed at sea level is roughly estimated as follows:

$$V_{\max Sea100} = \sqrt{\frac{2 * 0.35 * 131200 * 1}{1.225 \times 0.02 \times 108.55}}$$

- $V_{\max Sea100}$ is 185.93 m/s (669.39 km/h; 361.43 kn)

This figure is probably a bit optimistic, as the maximum power is delivered at near-zero speed, at take-off, and the thrust diminishes as speed increases. But it serves as a starting point, and works toward the most critical speed, which is the cruise speed at cruising altitude.

The maximum speed at cruising altitude is calculated as follows:

$$V_{\max Alt100} = \sqrt{\frac{2 * 0.6 * 31500 * 1}{0.299 \times 0.02 \times 108.55}}$$

- $V_{\max Alt100}$ is 241.47 m/s (869.29 km/h; 469.38 kn)

The cruise speed at sea level is roughly estimated as follows:

$$V_{cruiseSea85} = \sqrt{\frac{2 * 0.35 * 131200 * 0.85}{1.225 \times 0.02 \times 108.55}}$$

- $V_{cruiseSea85}$ is 171.42 m/s (617.12 km/h; 333.22 kn)

This figure is also probably optimistic, for the same reasons given above for the maximum speed at sea level.

The most critical speed figure is the cruise speed at cruising altitude. It is calculated as follows:

$$V_{cruiseAlt85} = \sqrt{\frac{2 * 0.6 * 31500 * 0.85}{0.299 \times 0.02 \times 108.55}}$$

- $V_{cruiseAlt85}$ is 222.62 m/s (801.44 km/h; 432.75 kn)

This figure is around 7.8% below the target cruise speed of 466.7 kn. Considering that the propulsive efficiency, power at cruising altitude and drag coefficient have all been roughly estimated (and mostly conservatively), additional detail optimisation should see this target reached. A slightly smaller wing will also result in a speed increase. For the purposes of this concept design, the calculated figure is acceptably close.

K.1.1.6. Maximum Fuel Weight

The determination of the total fuel load is calculated utilising a method detailed in Desktop Aeronautics “Aircraft Design: Synthesis and Analysis”, version 1.2, September 2006. Chapter 11.4 of this tool details the method used to determine the range at cruise speed, and utilises the fuel load to do this. Since we know the range we want to attain, as well as the cruise speed, we can now determine the fuel load required. The final equation used is:

$$R = \frac{V}{c} \frac{L}{D} \ln \frac{W_i}{W_f}, \text{ where}$$

- R is the cruise range (7,933.5 nmi)
- V is the cruise speed at cruising altitude (222.62 m/s; 432.75 nmi/h)

- c is the Specific Fuel Consumption of the powerplant at cruising altitude
- L/D is lift-to-drag ratio
- W_i is the estimated weight at the beginning of the cruise segment
- W_f is the estimated weight at the end of the cruise segment

The Specific Fuel Consumption for the BMW/Rolls-Royce BR710 is 0.681 lb/lbf.h at cruise altitude (sourced from document “European Commission – State aid N 195/2007 (Germany), Individual R&D-aid for Rolls-Royce Deutschland – BR725 project”).

The value for V/c is calculated as:

$$\frac{V}{c} = \frac{432.75}{0.681}$$

- V/c is 635.5 nmi

The lift-to drag ratio is calculated from:

$$\frac{L}{D} = \frac{1}{2} \sqrt{\frac{\pi \times AR_{wing} \times 0.8}{Cd_0}}$$

Therefore, the lift-to-drag ratio for this design is:

$$\frac{L}{D} = 0.5 * \sqrt{\frac{\pi * 7 * 0.8}{0.02}}$$

- L/D is 14.84

W_i and W_f are calculated from:

$$W_i = W_{tow} - \frac{1}{2} x W_{maneuver} - W_{cl}, \text{ and}$$

$$W_f = W_{zfw} + W_{reserves} + \frac{1}{2} x W_{maneuver}, \text{ where}$$

- W_{tow} is the maximum take-off (all-up) weight (45,000 kg)
- W_{maneuver} is estimated as 0.7% of the take-off weight (315 kg)
- W_{cl} is taken as 1.3% of the take-off weight (from the plot in Section 11.3 of the reference material) (585 kg)
- W_{zfw} is the zero-fuel weight, or weight of the aircraft minus fuel (17,666 kg)
- W_{reserves} is estimated as 8% of the zero fuel weight (1,413 kg)

Using Excel, and through an iterative process, a value of 27,480 kg is determined for the total fuel required to reach a value for R of 7,933.64 nmi. This value is virtually equal to (marginally better than) the target value of 7,933.5 nmi. This provides a zero fuel weight of 17,520 kg ($W_{\text{MAU}} - W_{\text{fuel}}$).

For completeness, the values for W_i and W_f are provided as follows:

$$W_i = 45000 - 0.5 * 315 - 585$$

- W_i is 44,257.5 kg

$$W_f = 17,520 + 1,413 + 0.5 * 315$$

- W_f is 19,079.1 kg

In addition:

- W_i / W_f is 2.32

Then:

$$R = 635.5 * 14.84 * \ln 2.32$$

- This provides the aforementioned cruise range of 7,933.64 nmi.

To summarise, a fuel load of 27,480 kg is required to allow the UA to travel a total of 7,933.64 nmi at a cruise speed of 222.62 m/s (801.44 km/h; 432.75 kn), at a cruising altitude of 40,000 ft.

K.1.1.7. Take-off Distance

The total take-off distance is the summation of the ground run, plus the horizontal distance required by the aircraft while airborne until it clears a height of 15.3 m (50 ft). This height is a standard, and is specified to ensure the ascending aircraft clears obstacles (trees, power lines, etc) at the end of the runway.

Therefore:

$$S_{TO} = S_{run} + S_{air}, \text{ where}$$

- S_{TO} is the total take-off distance
- S_{run} is the ground run portion
- S_{air} is the distance from lift-off to the 15.3 m clearance

The ground run portion is calculated from:

$$S_{run} = \frac{V_{lof}^2 \div (2 \times g)}{(T \div W) - \mu^1}, \text{ where}$$

- V_{lof} is the lift-off speed, calculated as $1.2 \times V_{stallSea}$
- W is the maximum take-off (all-up) weight (45,000 kg)
- T is the take-off thrust at sea level
- μ^1 is the friction factor, calculated from:

$$\mu^1 = \mu + \left(0.72 \times \left(\frac{C_{d0}}{C_{lmax}} \right) \right), \text{ where}$$

- μ is 0.02 for concrete runways and 0.05 for short-grass runways. The UA under consideration for this design study will operate from concrete runways, hence μ is 0.02. Therefore, μ^1 is calculated as:

$$\mu^1 = 0.02 + \left(0.72 \times \left(\frac{0.02}{2} \right) \right)$$

- μ^1 is 0.027

Therefore, the ground run portion is calculated as:

$$S_{run} = \frac{(1.2 * 57.62)^2 / (2 * 9.81)}{((131220 / 9.81) / 45000) - 0.027}$$

- S_{run} is 910 m (rounded)

The airborne portion is calculated from:

$$S_{air} = \frac{V_{lof}^2}{2 \times g} + \frac{h_{to}}{v_{lof}}, \text{ where}$$

- h_{to} is the height to clear, i.e. 15.3 m
- v_{lof} is calculated from:

$$v_{lof} = \left(0.9 \times \frac{T}{W} \right) - \left(\frac{0.3}{AR_{Wing}} \right), \text{ therefore}$$

$$v_{lof} = \left(0.9 * \frac{(131220 / 9.81)}{45000} \right) - \left(\frac{0.3}{7} \right)$$

- v_{lof} is 0.225

Therefore, the airborne portion is calculated as:

$$S_{air} = \frac{(1.2 * 57.62)^2}{(2 * 9.81)} + \frac{15.3}{0.225}$$

- S_{air} is 320 m (rounded)

The total take-off distance, S_{TO} , is therefore calculated as:

$$S_{TO} = 910 + 320$$

- S_{TO} is 1,230 m

K.1.1.8. Landing Distance

As for the take-of run, the total landing distance is the summation of the horizontal distance covered by the aircraft from a height of 15.3 m (50 ft) until touchdown, plus the ground run.

Therefore:

$$S_{LAND} = S_{air} + S_{run}, \text{ where}$$

- S_{LAND} is the total landing distance
- S_{air} is the distance from 15.3 m to touchdown
- S_{run} is the ground run portion to standstill

The airborne portion is calculated from:

$$S_{air} = \frac{1}{0.1} \times \left(\frac{V_a^2 - V_{td}^2}{2 \times g} + h_{land} \right), \text{ where}$$

- V_a is the approach speed, estimated as $1.3 \times V_{stallSea}$
- V_{td} is the touchdown speed, calculated as:

$$V_{td} = \sqrt{0.9 \times V_a^2}, \text{ therefore}$$

$$V_{td} = \sqrt{0.9 * (1.3 * 57.62)^2}$$

- V_{td} is 71.06 m/s
- h_{land} is the 15.3 m height to clear

Therefore, the airborne portion is calculated as:

$$S_{air} = \frac{1}{0.1} * \left(\frac{(1.3 * 57.62)^2 - 71.06^2}{2 * 9.81} + 15.3 \right)$$

- S_{air} is 440 m (rounded)

The ground run portion is calculated from:

$$S_{run} = \frac{V_{td}^2}{2 * a}, \text{ where}$$

- a is $9.81 \times f_r$
- f_r is the retardation factor, estimated as 0.2 for aircraft without brakes, and 0.3 for an aircraft equipped with brakes

Therefore, the ground run is calculated as:

$$S_{run} = \frac{71.06^2}{2 * 9.81 * 0.3}$$

- S_{run} is 860 m (rounded)

The total landing distance, S_{LAND} , is therefore calculated as:

$$S_{LAND} = 440 + 860$$

- S_{LAND} is 1,300 m

K.1.2. Aerodynamic Characteristics and Sizing

The second calculation set focuses on determining the aerodynamic characteristics and associated design for the UA.

K.1.2.1 Horizontal Tail Surfaces

The tail surfaces are primarily used to provide longitudinal stability, directional stability and yawing and pitching control. The method employed for the calculation of the tail surface aerodynamic characteristics and sizes uses the statistically-determined “tail-volume coefficient”.

The tail-volume coefficient is calculated from:

$$V_t = \frac{S_t \times I_t}{S \times c}, \text{ where}$$

- V_t is the horizontal tail volume coefficient. This value has been determined statistically to be 0.35 to 0.4 for an aircraft with an un-flapped main wing, and 0.45 to 0.55 for an aircraft with a flapped main wing. This UA will have a flapped main wing, thus V_t lies between 0.45 and 0.55; 0.55 for STOL configurations, 0.45 for high-speed racing applications. We select V_t as 0.5 for this application as a first iteration.
- S_t is the area of the horizontal tail
- I_t is the distance between the UA centre of gravity and the quarter chord position on the horizontal tail surface
- S is the main wing area
- c is the mean aerodynamic chord of the main wing

For the calculation of I_t , the position of the centre of gravity is required. Since this position is as yet unknown, it is estimated to be at the quarter-chord position of the main wing. The position of the main wing, where it attaches to the fuselage, is chosen to be similar to the position of the Gulfstream G550. In this configuration, the quarter chord position, and thus the centre of gravity, lies 10.4 m from the front of the UA.

Many of the dimensions used henceforth are estimated (chosen), or are graphically determined (measured).

The average chord of the main wing was previously calculated as 3.94 m, using the wing area and wing span. This value is better expressed as the mean aerodynamic chord, or MAC, and is calculated from:

$$MAC = \frac{2}{3} \times \left[c_r + c_t - \frac{c_r \times c_t}{c_r + c_t} \right], \text{ where}$$

- c_r is the wing root chord, and is 5.5 m for the main wing
- c_t is the wing tip chord, and is 2.38 m for the main wing

Therefore, the MAC for the main wing is calculated as:

$$C_{MAC} = \frac{2}{3} * \left[5.5 + 2.38 - \frac{5.5 * 2.38}{5.5 + 2.38} \right]$$

- C_{MAC} is 4.14 m

The value for l_t is determined graphically as 8.8 m. It is measured from the estimated centre of gravity, to the quarter-chord position of the horizontal tail surface.

The area of the horizontal tail surface is calculated by rearranging the tail-volume coefficient formula into:

$$S_t = \frac{V_t \times S \times C_{MAC}}{l_t}$$

Therefore, the area of the horizontal tail is calculated as:

$$S_t = \frac{0.5 * 108.55 * 4.14}{8.8}$$

- S_t is 25.56 m²

The span of the horizontal tail is determined from:

$$b_t = \sqrt{AR_t \times S_t}, \text{ where}$$

- AR_t is the horizontal tail aspect ratio. Statistically determined, the horizontal tail aspect ratio is 50 to 70% of the main wing. Using a value of 60%, AR_t is 4.2.

Therefore, the span of the horizontal tail is calculated as:

$$b_t = \sqrt{4.2 * 25.56}$$

- b_t is 10.36 m

The average chord of the horizontal tail is calculated from:

$$c_{aHor} = \frac{S_t}{b_t}$$

Therefore, the average chord of the horizontal tail is calculated as:

$$c_{aHor} = \frac{25.56}{10.36}$$

- c_{aHor} is 2.47 m

The root chord c_{rHor} for the horizontal tail is chosen as 3.2 m. The tip chord c_{tHor} is calculated from:

$$c_{tHor} = (c_{aHor} \times 2) - c_{rHor}$$

Therefore, the tip chord of the horizontal tail is calculated as:

$$c_{tHor} = (2.47 \times 2) - 3.2$$

- c_{tHor} is 1.73 m

The average elevator chord for the horizontal tail is estimated at 40% of the average chord for the horizontal tail. Therefore:

- c_{aElev} is 0.99 m

For the purposes of this concept design, trim tabs will not be calculated.

K.1.2.2 Vertical Tail Surface

For the purposes of this concept design, a conventional single vertical tail is adopted. The tail-volume coefficient method is also used to determine the aerodynamic characteristics of the vertical tail fin.

The area of the vertical tail fin surface is calculated by rearranging the tail-volume coefficient formula into:

$$S_f = \frac{V_f \times S_{wing} \times b_{wing}}{I_f}, \text{ where}$$

- V_f is the vertical tail fin volume coefficient. This value has been determined statistically to be 0.035 to 0.04; 0.035 for longer tail sections, up to 0.04 for short tail sections, pusher- and multi-engine wing-mounted arrangements. We select V_f as 0.035 for this application as a first iteration.
- b_{wing} is the main wing span, calculated as 27.57 m
- I_f is the distance between the UA centre of gravity and the quarter chord position on the vertical tail surface

The value for I_f is determined graphically as 8.9 m. It is measured from the estimated centre of gravity, to the quarter-chord position of the vertical tail fin surface.

Therefore, the area of the vertical tail fin is calculated as:

$$S_f = \frac{0.035 * 108.55 * 27.57}{8.9}$$

- S_f is 11.77 m²

The height of the vertical tail fin is determined from:

$$h_f = \sqrt{AR_f \times S_f}, \text{ where}$$

- AR_f is the vertical tail fin aspect ratio. Statistically determined, most vertical tail fin aspect ratios are between 1 and 1.8, with small aspect ratios producing short, and larger aspects ratios producing taller fins. For the purposes of this concept design an AR_f is chosen as 1.4.

Therefore, the height of the vertical tail fin is calculated as:

$$h_f = \sqrt{1.4 * 11.77}$$

- h_f is 4.06 m

This is the height above the fuselage.

The average chord of the vertical tail fin is calculated from:

$$c_{aFin} = \frac{S_f}{b_f}$$

Therefore, the average chord of the horizontal tail is calculated as:

$$c_{aFin} = \frac{11.77}{4.06}$$

- c_{aFin} is 2.9 m

The root chord c_{rFin} for the vertical tail fin is chosen as 4.1 m. The tip chord c_{tFin} is calculated from:

$$c_{tFin} = (c_{aFin} \times 2) - c_{rFin}$$

Therefore, the tip chord of the horizontal tail is calculated as:

$$c_{tHor} = (2.9 \times 2) - 4.1$$

- c_{tFin} is 1.7 m

The average rudder chord for the vertical tail fin is estimated at 30% of the average chord for the vertical tail fin. Therefore:

- c_{aRud} is 0.87 m

K.1.2.3 Flaps

Flaps are used to increase lift and drag during certain crucial stages of flight, including take-off, landing and low speed flight. Flaps generally increase the wing area, thereby increasing lift. Flaps are divided into two primary categories:

- Leading Edge flaps

- Trailing Edge flaps

For the purposes of this concept design, Leading Edge flaps will not be considered.

Trailing Edge flaps are further divided into several types, the most prominent and widely used being:

- Plain flaps
- Split flaps
- Slotted (single, double, triple) flaps
- Fowler flaps

Although relatively complex, Fowler flaps provide the greatest benefit of lift over drag. Fowler flaps extend rearwards on tracks and only deflect downward at the very end of travel, thereby reducing drag, while continuously increasing lift, during extension. The desired lift coefficient for the UA is 2.0, and Table K.2^[110] shows that, without a Leading Edge flap (slat), only a Fowler flap will provide this for both take-off and landing.

DEVICE		Typical Flap Angle, degrees		C_{Lmax}	
Trailing Edge Flaps	Leading Edge	Take-off	Landing	Take-off	Landing
Plain	--	20	60	1.4 - 1.6	1.7 - 2.4
Single Slotted	--	20	40	1.5 - 1.7	1.8 - 2.2
Fowler	--	15	40	2.0 - 2.2	2.5 - 2.9
Double Slotted	--	20	50	1.7 - 1.9	2.3 - 2.5
	Slat	20	50	2.3 - 2.6	2.8 - 3.2
Triple Slotted	Slat	20	40	2.4 - 2.7	3.2 - 3.5

Table K.2: Effective Lift Coefficient Values^[110]

For the purposes of this concept design, a Fowler flap, with a chord 25% of the main wing chord (as for the ailerons), is chosen. The flaps will run from the aileron root to the fuselage.

Appendix L

L. Unmanned Aircraft Design Analysis: Daniel P. Raymer

Appendix L provides the detail analysis for the concept design of the Unmanned Aircraft, as presented in the book by Daniel P. Raymer entitled “Aircraft Design – A Conceptual Approach”^[110].

L.1. Method 2: Daniel P. Raymer: Aircraft Design – A Conceptual Approach^[110]

The second method used to determine the general size, weights and power requirements for the UA utilised the methods as described in Daniel P. Raymer’s book “Aircraft Design – A Conceptual Approach”^[110]. As for the first method, where assumptions were made, it has been clearly stated, with logical deductions.

The actual calculations were performed in Excel. Results are summarized in Chapter 14.

L.1.1. Mission Profile

As a prelude to the design work, the basic Mission Profile is defined. Parameters are deduced from the performance requirements, as set out in Part 1 of this thesis. The Mission Profile is graphically depicted in Figure L.1.

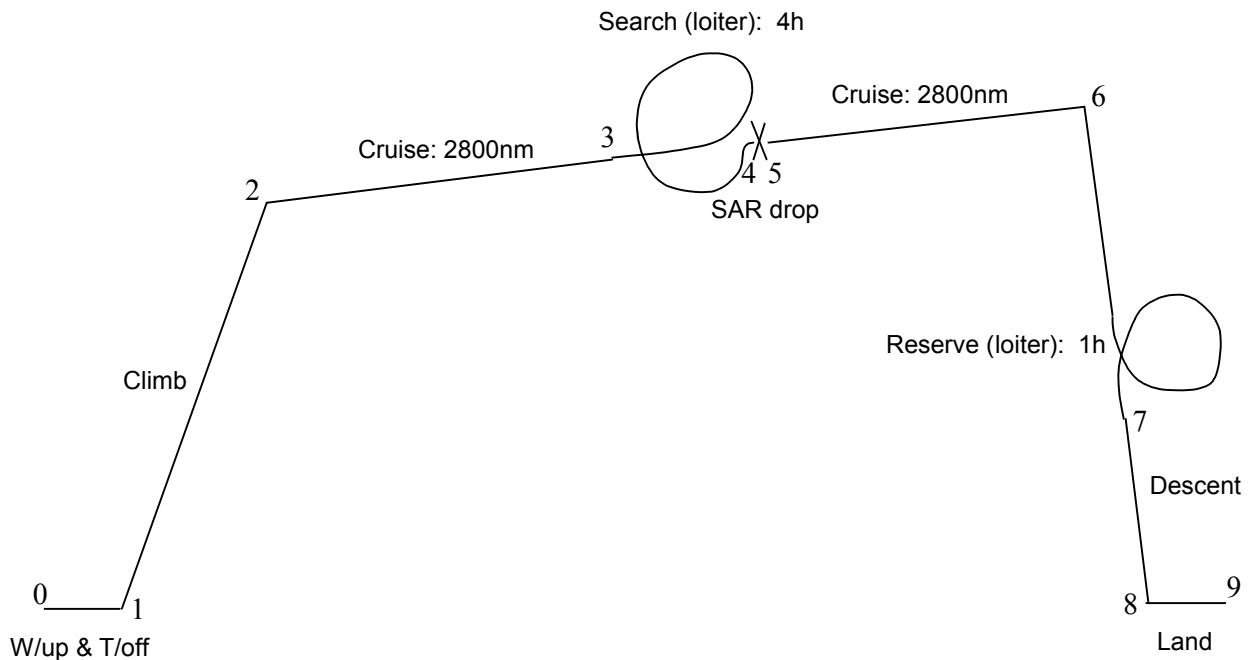


Figure L.1: Basic Mission Profile

L.1.2. Predefined Performance Figures

In conjunction with the definition of the Mission Profile, the following performance figures are predefined:

- Cruise Altitude: 35,000 ft
- Maximum Cruise Speed V_{cruise} : 467 kn (788.3 ft/s, M 0.81 at 35,000 ft)
- Maximum Speed: M 0.9 (estimated)

L.1.3. Historical Data

The Source Material utilised for this design method makes use of Historical Data for many of the calculations. Method 1 revealed that the UA will be similar in size and weight to a large Business Jet. As a result, in selection of Historical Data from the tables and graphs provided, the data for “Jet Transport”, “Airliner”, “Commercial” or “Large Transport” was used in all but a few cases. One exception was the selection of Historical Data for “Bomber” in calculation of the wing aspect ratio, as this data provided a slightly larger

aspect ratio, which was seen to be potentially beneficial for the long loiter time required over the Search Location.

L.1.4. Lift-to-Drag Ratio Estimation

The Lift-to-Drag Ratio (L/D) is estimated as follows:

The Aspect Ratio for the wing (AR_w) is determined from historical data as follows (Table 4.1):

$$AR_w = a \times M_{\max}^c$$

Values for a and c are chosen from Table 4.1 as follows:

- a is 5.57
- c is -1.075

Therefore:

$$AR_w = 5.57 * 0.9^{-1.075}$$

- AR_w is 7.0

From Figure 3.5, the Wetted Area Ratio (S_{wet}/S_{ref}) is selected for the Airliner and interpolated to be 6.3.

From Figure 3.6, the Wetted Aspect Ratio (WAR) is calculated as:

$$WAR = \frac{AR_w}{(S_{wet} / S_{ref})}$$

Therefore:

$$WAR = \frac{7.0}{6.3}$$

- WAR is 1.11

From Figure 3.6, the maximum L/D is read off as 16.5, using the curve for Civil Jets as a guide.

Therefore:

$$L / D_{\max} = L / D_{\text{loiter}} \text{ for jet aircraft (p. 23)}$$

- L/D_{loiter} is 16.5

$$L / D_{\text{cruise}} = 0.866 \times L / D_{\text{loiter}} \text{ for jet aircraft (p. 23)}$$

- $L/D_{\text{cruise}} = 14.3$

These L/D values are first-order of estimation, and are used for initial Thrust-to-Weight Ratio estimations.

L.1.5. Thrust-to-Weight Ratio Estimation

The Thrust-to-Weight Ratio (T/W) is estimated as follows:

Equation 5.2 provides an estimation of the Cruise T/W (T/W_{cruise}) as follows:

$$T / W_{\text{cruise}} = \frac{1}{L / D_{\text{cruise}}}$$

Therefore:

$$T / W_{\text{cruise}} = \frac{1}{14.3}$$

- T/W_{cruise} is 0.070

The T/W at take-off (T/W_0) is calculated from Equation 5.3:

$$T / W_0 = T / W_{\text{cruise}} \times \frac{W_{\text{cruise}}}{W_{\text{to}}} \times \frac{T_{\text{to}}}{T_{\text{cruise}}}$$

The ratio between initial cruise weight (W_{cruise}) and take-off weight (W_{to}) is estimated to be in the order of 0.956 (p. 82). The ratio between take-off thrust and cruise thrust for a jet engine varies between different engine models.

However, an average value of 5.2 has been calculated by comparing nine different high bypass ratio turbofan engines.

Therefore:

$$T / W_0 = 0.070 * 0.956 * 5.2$$

- T/W_0 is 0.35

L.1.6. Wing Loading

This sub-section calculates the Wing Loading (W/S) at take-off. The W/S is used, along with the estimated T/W_0 and L/D, to determine the maximum Take-off Weight, and other key parameters.

Wing Loading is calculated for different portions of flight, typically at Stall, during landing and take-off, during cruise, loiter, at instantaneous turn, sustained turn, combat, etc. In consideration of the mission profile and projected operational requirements for this UA, only the following portions were considered:

- Stall
- Take-off
- Landing
- Cruise
- Loiter

All values are compared with Historical Values (Table 5.5). Calculated values differing far from the Historical Value are ignored – this is particularly true for those calculated during cruise and loiter (p. 94). The lowest remaining calculated value is then chosen as the benchmark. The Wing Loading chosen for the design should always be \leq the smallest calculated value (p. 100), barring those far from the Historical Value.

L.1.6.1. Wing Loading: Historical Value

From Table 5.5, the Historical Value for W/S_{to} is 120 lb/ft².

L.1.6.2. Wing Loading: Stall

The wing loading at stall speed is calculated from Equation 5.6 as follows:

$$W / S_{stall} = 0.5 \times \rho \times V_{stall}^2 \times C_{Lmax}, \text{ where:}$$

- V_{stall} is the stall speed in ft/s;
- C_{Lmax} is the Maximum Lift Coefficient

For take-off conditions (stall can take place during take-off) the air density is taken at sea-level conditions. Therefore:

- ρ_{sea} is 1.225 kg/m³, or 0.00238 slugs/ft³

The stall speed is calculated as a factor of the approach speed (p. 85). The approach speed (V_{appr}) is estimated to be 299 ft/s. The stall speed is estimated as follows:

$$V_{stall} = \frac{V_{appr}}{1.3}$$

Therefore:

$$V_{stall} = \frac{299}{1.3}$$

- V_{stall} is 230 ft/s

The Maximum Lift Coefficient (C_{Lmax}) is estimated from Figure 5.3 as 2, using a value of 27 degrees for the Quarter Chord Angle (initial estimate).

Therefore:

$$W / S_{stall} = 0.5 * 0.00238 * 230^2 * 2$$

- W/S_{stall} at take-off conditions is 125.9 lb/ft^2

L.1.6.3. Wing Loading: Take-off

The wing loading at take-off is calculated from Equation 5.9 as follows:

$$W / S_{to} = TOP \times \sigma \times C_{Lto} \times T / W_0, \text{ where:}$$

- TOP is the Take-Off Parameter
- C_{Lto} is the Take-Off Lift Coefficient

Figure 5.4 is used to determine the Take-off Parameter (TOP). The take-off distance is required for this, and is estimated as slightly less than the landing distance. The landing distance is estimated as follows (p. 90):

$$S_{\text{landing}} = 0.3 \times V_{\text{appr}} (\text{knots})^2$$

- V_{appr} is $299 \text{ ft/s} = 177.307 \text{ kn}$

Therefore:

$$S_{\text{landing}} = 0.3 \times 177.307^2$$

- S_{landing} is 9431.33 ft
- Therefore, S_{to} is estimated at 9000 ft

Thus, from Figure 5.4, for a 2-engined aircraft and balanced field length conditions, the TOP is estimated at 220.

The density ratio (σ) at sea level is 1.

The Take-off Lift Coefficient (C_{Lto}) is calculated as follows (p. 89):

$$C_{Lto} = \frac{C_{L\text{max}}}{1.21}$$

Therefore:

$$C_{Lto} = \frac{2}{1.21}$$

- C_{Lto} is 1.653

Therefore:

$$W / S_{to} = 220 * 1 * 1.653 * 0.35$$

- W/S_{to} is 126.82 lb/ft²

L.1.6.4. Wing Loading: Landing

The wing loading at landing is calculated from Equation 5.11 (and reference on p. 91) as follows:

$$S_{landing} = 1.67 \times \left[80 \times W / S_{landing} \times \left(\frac{1}{\sigma \times C_{Lmax}} \right) + S_a \right], \text{ where:}$$

- S_a is the obstacle clearing distance in ft

Re-arranging equation 5.11, the Wing Loading is calculated as:

$$W / S_{landing} = \left(\frac{1}{80} \right) \times (0.6 \times S_{landing} - S_a) \times (\sigma \times C_{Lmax})$$

S_a is 1000 ft for an Airliner descending with a 3 degree glide slope (p. 91).

Therefore:

$$W / S_{landing} = \left(\frac{1}{80} \right) * (0.6 * 9431.33 - 1000) * (1 * 2)$$

- $W/S_{landing}$ is 116.47 lb/ft²

Converting to take-off conditions (p. 91):

$$W / S_{to} = \frac{W / S_{landing}}{0.85}$$

- $W/S_{landing}$ at take-off conditions is 137.024 lb/ft²

L.1.6.5. Wing Loading: Cruise

The wing loading at cruise is calculated from Equation 5.14 as follows:

$$W / S_{cruise} = q \times \sqrt{\frac{\pi * AR_w \times e \times C_{D0}}{3}}, \text{ where:}$$

- q is the Dynamic Pressure ($0.5\rho V^2$) at cruise conditions (Equation 12.3);
- e is the Oswald Efficiency Factor, estimated to 0.8 for non-fighter-type aircraft for Initial Sizing (p. 92);
- C_{D0} is the Zero-lift Drag Coefficient, and is estimated as 0.015 for Initial Sizing (p. 92)

The air density (ρ) at cruise altitude (35,000 ft) is 0.0007382 slugs/ft³.

Therefore:

$$W / S_{cruise} = 0.5 * 0.0007382 * 788.3^2 * \sqrt{\frac{\pi * 7.0 * 0.8 * 0.015}{3}}$$

- W/S_{cruise} is 67.955 lb/ft²

Converting to take-off conditions (p. 94):

$$W / S_{to} = \frac{W / S_{cruise}}{0.85}$$

- W/S_{cruise} at take-off conditions is 79.947 lb/ft²

This value is far lower than the Historical Value (120 lb/ft²) and is therefore IGNORED for final selection of W/S.

L.1.6.6. Wing Loading: Loiter

The wing loading at loiter is calculated from Equation 5.15 as follows:

$$W / S_{loiter} = q \times \sqrt{\pi * AR_w \times e \times C_{D0}}, \text{ where:}$$

- q is the Dynamic Pressure ($0.5\rho V^2$) at loiter conditions (Equation 12.3).

The loiter speed (V_{loiter}) is estimated at 200 kn, or 337 ft/s (p. 94).

Therefore:

$$W / S_{loiter} = 0.5 * 0.0007382 * 337^2 * \sqrt{\pi * 7.0 * 0.8 * 0.015}$$

- W/S_{loiter} is 21.51 lb/ft²

Converting to take-off conditions (p. 94):

$$W / S_{to} = \frac{W / S_{loiter}}{0.85}$$

- W/S_{loiter} at take-off conditions is 25.307 lb/ft²

This value is far lower than the Historical Value (120 lb/ft²) and is therefore IGNORED for final selection of W/S .

L.1.6.7. Wing Loading: Selection

From the above calculations, four values for W/S_{to} are presented for final selection:

- Historical: 120 lb/ft²
- Stall: 125.9 lb/ft²
- Take-off: 126.82 lb/ft²
- Landing: 137.024 lb/ft²

The lowest value from the four values calculated and listed above is 125.9 lb/ft². Therefore, W/S_{to} should be selected to be ≤ 125.9 (p. 100).

- W/S_{to} is selected to be 120 lb/ft²

L.1.7. Take-off Weight

The estimation of maximum take-off weight follows an iterative process, utilising one of two methods. The first method makes use of the following equations (Equation 6.1 and Table 6.1):

$$W_0 = \frac{W_{crew} + W_{payload}}{1 - (W_f / W_0) - (W_e / W_0)}, \text{ and}$$

$$W_e / W_0 = \{a + b \times W_0^{C1} \times AR_w^{C2} \times (T / W_0)^{C3} \times (W / S_{to})^{C4} \times M_{max}^{C5}\} \times K_{VS}$$

The second method makes use of the following equations (Equation 6.4 and Table 6.1):

$$W_0 = \frac{W_{crew} + W_{fixed_payload} + W_{dropped_payload} + W_{fuel}}{1 - (W_e / W_0)}, \text{ and}$$

$$W_e / W_0 = \{a + b \times W_0^{C1} \times AR_w^{C2} \times (T / W_0)^{C3} \times (W / S_{to})^{C4} \times M_{max}^{C5}\} \times K_{VS}$$

The first method assumes no dropped payloads, and the fuel weight is expressed as a fraction of the take-off weight –

$$W_f / W_0 = 1 - W_x / W_0, \text{ where:}$$

- x is the number of “segments” defined for the entire Mission Profile (9 for this design)

The second method takes into account the weight of dropped payloads, and calculates the fuel weight directly.

The second method is preferable if dropped payloads are to be accounted for, and leads to more accurate results. For this design, both methods gave the same result. The second method will be described in this text, although both were employed and the first method process is accessible in the Excel spreadsheet.

L.1.7.1. Basic Process

The basic iterative process followed was as follows.

Two main Equations were utilised in the iteration to determine take-off weight (W_0). An initial value for W_0 is guessed, say "GUESS1". This value is inserted into the following equation to determine the Empty Weight Fraction (W_e/W_0) (Table 6.1):

$$W_e / W_0 = \{a + b \times W_0^{C1} \times AR_w^{C2} \times (T / W_0)^{C3} \times (W / S_{to})^{C4} \times M_{\max}^{C5}\} \times K_{VS}, \text{ where:}$$

- a is 0.32 for a Jet Transport
- b is 0.66 for a Jet Transport
- C1 is -0.13 for a Jet Transport
- C2 is 0.3 for a Jet Transport
- C3 is 0.06 for a Jet Transport
- C4 is -0.05 for a Jet Transport
- C5 is 0.05 for a Jet Transport
- K_{VS} is 1 for a non-variable-sweep wing aircraft
- AR_w is 7.0, as previously determined
- T/W_0 is 0.35, as previously determined
- W/S_{to} is 120 lb/ft², as previously determined
- M_{\max} is 0.9, as previously selected
- W_0 is "GUESS1"

The Empty Weight Fraction (W_e/W_0) as calculated is inserted into the following equation, along with the other weights, to determine W_{0_calc} (Equation 6.4):

$$W_{0_calc} = \frac{W_{crew} + W_{fixed_payload} + W_{dropped_payload} + W_{fuel}}{1 - (W_e / W_0)}$$

W_0 “calculated” is compared with W_0 “GUESS1”. The value “GUESS1” for W_0 is changed to another value (“GUESS2”), a new value for W_e/W_0 is calculated, and a new value for W_0 is calculated using Equation 6.4. This process is repeated until W_0 “GUESSX” = W_0 “calculated”, which then yields the final value for take-off weight, W_0 .

L.1.7.2. Weights

The values for the weights in Equation 6.4 are determined as follows:

- W_{crew} is 0 lb, as this is an unmanned vehicle
- $W_{fixed_payload}$ is estimated at 3,500 lb (FLIR sensor, Maritime Search Radar components, SAR Direction Finder, general avionics, radios, SATCOM and Line-of-Sight antenna equipment)
- $W_{dropped_payload}$ is estimated at 2,900 lb (8x Marine Location Markers, 6x Aid Life Supply Canisters)
- W_{fuel} is calculated directly by using the initial guessed value for W_0 (“GUESS1”). W_{fuel} is calculated by firstly determining the Mission Segment Weight Fractions, i.e. the weight of the aircraft at the end of each Mission Segment vs the weight at the start of each Mission Segment (W_x/W_{x-1} for each of x Mission Segments – 9 for this design). The fuel burned (weight lost) per Mission Segment is then calculated as $1 - W_x/W_{x-1}$ for each Segment. The actual fuel weight (lb) per Segment is then determined using the initial value for take-off weight (W_0) “GUESS1” at the start of Segment 1, re-calculating the weight for Section 2, determining the fuel weight for Section 2, and so on, until all Segments (9) have been covered. The total fuel burned for the entire Mission Profile is then the sum of the fuel burned during each of the Segments. This value is multiplied by 1.06 to account for reserves, and is used as the value for W_{fuel} in equation 6.4. The entire process is

repeated for each guess of W_0 "GUESS" – Excel makes the process easier.

L.1.7.3. W_0 Determination: W_0 Guess

Using an iterative process in Excel, many values for W_0 Guess were selected until W_0 Guess equalled W_0 Calculated. To help illustrate the process, the final value for W_0 will be used.

Therefore, for the purposes of this description:

- W_0 GUESS is 142,639 lb

L.1.7.4. W_0 Determination: Mission Segment Weight Fractions

The Mission Profile for this design designates 9 distinct Mission Segments (MS):

- MS₀₋₁: Warm-up and Take-off
- MS₁₋₂: Climb
- MS₂₋₃: Cruise
- MS₃₋₄: Search (loiter)
- MS₄₋₅: SAR drop
- MS₅₋₆: Cruise
- MS₆₋₇: Reserve (loiter)
- MS₇₋₈: Descent
- MS₈₋₉: Land

During each MS weight-loss is due to fuel being burned, except for MS₄₋₅, where weight-loss is due to SAR equipment being dropped to survivors. The weight difference per MS is expressed as a fraction of the total weight at the

end of the Segment vs the total weight at the start of the Segment, or W_x/W_{x-1} . These Weight Fractions are calculated as follows.

MS₀₋₁: Warm-up and Take-off

Determine Weight Fraction W_1/W_0 .

This Weight Fraction is estimated from Historical Values (Equation 6.8).

- W_1/W_0 is 0.97

MS₁₋₂: Climb

Determine Weight Fraction W_2/W_1 .

This Weight Fraction is determined as follows (Equation 6.9):

$$W_2 / W_{1_{climb_subsonic}} = 1.0065 - 0.0325 M_{cruise}$$

Therefore:

$$W_2 / W_1 = 1.0065 - 0.0325 * 0.81$$

- W_2/W_1 is 0.98

MS₂₋₃: Cruise

Determine Weight Fraction W_3/W_2 .

This Weight Fraction is determined as follows (Equation 6.11):

$$W_3 / W_{2_{cruise}} = EXP \frac{-R \times C}{V_{cruise} \times (L / D)_{cruise}}, \text{ where}$$

- R is the range in ft (2,800 nm, 17,013,123 ft)
- C is the Specific Fuel Consumption during cruise in l/s

The Specific Fuel Consumption is estimated from Table 3.3 for a high bypass ratio turbofan. For cruise conditions, C is estimated as 0.5 l/h, or 0.000138889 l/s.

A more accurate value for L/D_{cruise} can now be calculated, now that the take-off Wing Loading (W/S_{to}) is known. The W/S_{to} , however, needs to be converted to the equivalent W/S for cruise first, since the Wing Loading decreases as fuel is burned and total weight decreases (p. 106, p. 610, p. 611).

$$W / S_{cruise} = W / S_{to} \times W_x / W_{x-1}$$

Therefore:

$$W / S_{cruise} = 120 * 0.97 * 0.98$$

- W/S_{cruise} is 114.09 lb/ft²

L/D_{cruise} is determined as follows (Equation 6.13):

$$L / D_{cruise} = \frac{1}{\frac{q \times C_{D0}}{W / S_{cruise}} + \left(W / S_{cruise} \times \frac{1}{q \times \pi \times AR_w \times e} \right)}, \text{ where}$$

- q is the Dynamic Pressure at cruise conditions
- C_{D0} is 0.015, as previously estimated
- e is 0.8, as previously estimated
- W/S_{cruise} is 114.09 lb/ft²
- AR_w is 7.0, as previously estimated

Therefore:

$$L / D_{cruise} = \frac{1}{\frac{0.5 * 0.0007382 * 788.3^2 * 0.015}{114.09} + \left(114.09 * \frac{1}{0.5 * 0.0007382 * 788.3^2 * \pi * 7.0 * 0.8} \right)}$$

- L/D_{cruise} is 17.1

Therefore:

$$W_3 / W_2 = EXP \frac{-17013123 \times 0.000138889}{788.3 \times 17.1}$$

- W_3/W_2 is 0.84

MS₃₋₄: Search (loiter)

Determine Weight Fraction W_4/W_3 .

This Weight Fraction is determined as follows (Equation 6.14):

$$W_4 / W_{3_{search_loiter}} = EXP \frac{-E \times C}{(L/D)_{search_loiter}}, \text{ where}$$

- E is the search loiter time in seconds (4 h, 14,400 s)

More accurate values for V_{search_loiter} and L/D_{search_loiter} can also be calculated, using the W/S_{search_loiter} . W/S_{search_loiter} is determined as follows (p. 106, p. 610, p. 611):

$$W / S_{search_loiter} = W / S_{to} \times W_x / W_{x-1}$$

Therefore:

$$W / S_{search_loiter} = 120 * 0.97 * 0.98 * 0.84$$

- W/S_{search_loiter} is 95.74 lb/ft²

V_{search_loiter} is determined as follows (Equation 17.13, Equation 12.48, p. 613):

$$V_{search_loiter} = \sqrt{\left(\frac{2}{\rho} \times W / S_{search_loiter}\right) \times \sqrt{\frac{K}{C_{D0}}}}, \text{ where}$$

- K is $\frac{1}{\pi \times AR_w \times e}$

Therefore:

$$V_{search_loiter} = \sqrt{\left(\frac{2}{0.0007382} * 95.74\right)} * \sqrt{\frac{1}{\pi * 7.0 * 0.8 * 0.015}}$$

- V_{search_loiter} is 710.98 ft/s

This value is only slightly less than the cruise velocity of 788.3 ft/s. For this reason the value for Specific Fuel Consumption during this portion of loiter will be kept the same as for cruise, i.e. 0.5 l/h (0.000138889 l/s).

L/D_{search_loiter} is determined as follows (Equation 6.13):

$$L / D_{search_loiter} = \frac{1}{\frac{q \times C_{D0}}{W / S_{search_loiter}} + \left(W / S_{search_loiter} \times \frac{1}{q \times \pi \times AR_w \times e} \right)}, \text{ where}$$

- q is the Dynamic Pressure at search loiter conditions
- C_{D0} is 0.015, as previously estimated
- e is 0.8, as previously estimated
- W/S_{search_loiter} is 95.74 lb/ft²
- AR_w is 7.0, as previously estimated
- V_{search_loiter} is 710.98 ft/s

Therefore:

$$L / D_{search_loiter} = \frac{1}{\frac{0.5 * 0.0007382 * 710.98^2 * 0.015}{95.74} + \left(95.74 * \frac{1}{0.5 * 0.0007382 * 710.98^2 * \pi * 7.0 * 0.8} \right)}$$

- L/D_{search_loiter} is 17.1

Therefore:

$$W_4 / W_3 = EXP \frac{-14400 \times 0.000138889}{17.1}$$

- W_4/W_3 is 0.89

MS₄₋₅: SAR drop

Determine Weight Fraction W_5/W_4 .

It is assumed that the weight drop due to the release of the SAR equipment is instantaneous and that no weight loss due to fuel burn takes place. For this reason, the effect of W_5/W_4 can be IGNORED (p. 612).

MS₅₋₆: Cruise

Determine Weight Fraction W_6/W_5 .

Due to similarity, $W_6/W_5 \approx W_3/W_2$.

- W_6/W_5 is 0.84

MS₆₋₇: Reserve (loiter)

Determine Weight Fraction W_7/W_6 .

This Weight Fraction is determined as follows (Equation 6.14):

$$W_7 / W_{6_{res_loiter}} = EXP \frac{-E \times C}{(L/D)_{res_loiter}}, \text{ where}$$

- E is the reserve loiter time in seconds (1 h, 3,600 s)

More accurate values for V_{res_loiter} and L/D_{res_loiter} can also be calculated, using the W/S_{res_loiter} . W/S_{res_loiter} is determined as follows (p. 106, p. 610, p. 611):

$$W / S_{res_loiter} = W / S_{to} \times W_x / W_{x-1}$$

Therefore:

$$W / S_{res_loiter} = 120 * 0.97 * 0.98 * 0.84 * 0.89 * 0.84$$

- W/S_{res_loiter} is 71.48 lb/ft²

V_{res_loiter} is determined as follows (Equation 17.13, Equation 12.48, p. 613):

$$V_{res_loiter} = \sqrt{\left(\frac{2}{\rho} \times W / S_{res_loiter}\right)} \times \sqrt{\frac{K}{C_{D0}}}, \text{ where}$$

- K is $\frac{1}{\pi \times AR_w \times e}$
- ρ is at sea level

Therefore:

$$V_{res_loiter} = \sqrt{\left(\frac{2}{0.00238} \times 71.48\right)} \times \sqrt{\frac{1}{\pi \times 7.0 \times 0.8 \times 0.015}}$$

- V_{res_loiter} is 342.13 ft/s

This value is far less than the cruise velocity of 788.3 ft/s. For this reason the value for Specific Fuel Consumption (Table 3.3) during this portion of loiter will taken as 0.4 l/h (0.000111111 l/s).

L/D_{res_loiter} is determined as follows (Equation 6.13):

$$L / D_{res_loiter} = \frac{1}{\frac{q \times C_{D0}}{W / S_{res_loiter}} + \left(W / S_{res_loiter} \times \frac{1}{q \times \pi \times AR_w \times e} \right)}, \text{ where}$$

- q is the Dynamic Pressure at reserve loiter conditions
- C_{D0} is 0.015, as previously estimated
- e is 0.8, as previously estimated
- W/S_{res_loiter} is 71.48 lb/ft²
- AR_w is 7.0, as previously estimated
- V_{search_loiter} is 342.13 ft/s

Therefore:

$$L / D_{res_loiter} = \frac{1}{\frac{0.5 * 0.00238 * 342.13^2 * 0.015}{71.48} + \left(71.48 * \frac{1}{0.5 * 0.00238 * 342.13^2 * \pi * 7.0 * 0.8} \right)}$$

- L/D_{res_loiter} is 17.1

Therefore:

$$W_7 / W_6 = EXP \frac{-3600 \times 0.000111111}{17.1}$$

- W_7/W_6 is 0.98

MS₇₋₈: Descent

Determine Weight Fraction W_8/W_7 .

This Weight Fraction is estimated from Historical Values (Equation 6.22).

- W_8/W_7 is 0.993

MS₈₋₉: Land

Determine Weight Fraction W_9/W_8 .

This Weight Fraction is estimated from Historical Values (Equation 6.23, p. 16).

- W_9/W_8 is 0.997

To summarise the Mission Segment Weight Fractions:

- W_1/W_0 is 0.97
- W_2/W_1 is 0.98
- W_3/W_2 is 0.84
- W_4/W_3 is 0.89
- W_5/W_4 IGNORE

- W_6/W_5 is 0.84
- W_7/W_6 is 0.98
- W_8/W_7 is 0.993
- W_9/W_8 is 0.997

L.1.7.5. W_0 Determination: Fuel Weight per Mission Segment

MS₀₋₁: Warm-up and Take-off

Mission Segment Weight Fraction

- W_1/W_0 is 0.97

Fuel Burned Weight Fraction

- $1 - W_1/W_0$ is 0.03

Segment Start Weight (W_0)

- W_0 is W_0 "GUESS", and is guessed at 142,639 lb

Fuel Burned Weight MS₀₋₁

$$W_{f\ 0-1} = W_0 \times 0.03$$

$$W_{f\ 0-1} = 142693 * 0.03$$

- W_{f0-1} is 4,279.17 lb

Segment End Weight (W_1)

$$W_1 = W_0 - W_{f\ 0-1}$$

- W_1 is 138,359.83 lb

MS₁₋₂: Climb

Mission Segment Weight Fraction

- W_2/W_1 is 0.98

Fuel Burned Weight Fraction

- $1 - W_2/W_1$ is 0.02

Segment Start Weight (W_1)

- W_1 is 138,359.83 lb

Fuel Burned Weight MS_{1-2}

$$W_{f1-2} = W_1 \times 0.02$$

$$W_{f1-2} = 138359.83 \times 0.02$$

- W_{f1-2} is 2,743.38 lb

Segment End Weight (W_2)

$$W_2 = W_1 - W_{f1-2}$$

- W_2 is 135,616.45 lb

MS₂₋₃: Cruise

Mission Segment Weight Fraction

- W_3/W_2 is 0.84

Fuel Burned Weight Fraction

- $1 - W_3/W_2$ is 0.16

Segment Start Weight (W_2)

- W_2 is 135,616.45 lb

Fuel Burned Weight MS_{2-3}

$$W_{f_{2-3}} = W_2 \times 0.16$$

$$W_{f_{2-3}} = 135616.45 * 0.16$$

- $W_{f_{2-3}}$ is 21,808.94 lb

Segment End Weight (W_3)

$$W_3 = W_2 - W_{f_{2-3}}$$

- W_3 is 113,807.52 lb

MS₃₋₄: Search (loiter)

Mission Segment Weight Fraction

- W_4/W_3 is 0.89

Fuel Burned Weight Fraction

- $1 - W_4/W_3$ is 0.11

Segment Start Weight (W_3)

- W_3 is 113,807.52 lb

Fuel Burned Weight MS₃₋₄

$$W_{f_{3-4}} = W_3 \times 0.11$$

$$W_{f_{3-4}} = 113807.52 * 0.11$$

- $W_{f_{3-4}}$ is 12,558.08 lb

Segment End Weight (W_4)

$$W_4 = W_3 - W_{f_{3-4}}$$

- W_4 is 101,249.44 lb

MS₄₋₅: SAR drop

As no fuel is used during this Mission Segment, W_{f4-5} is IGNORED. The weight of the SAR stores dropped is also negligible compared to the weight of fuel burned, so is also ignored for the ensuing calculations.

MS₅₋₆: Cruise

Mission Segment Weight Fraction

- W_6/W_5 is 0.84

Fuel Burned Weight Fraction

- $1 - W_6/W_5$ is 0.16

Segment Start Weight (W_5)

- W_5 is equal to W_4 , which is 101,249.44 lb

Fuel Burned Weight MS₅₋₆

$$W_{f5-6} = W_5 \times 0.16$$

$$W_{f5-6} = 101249.44 \times 0.16$$

- W_{f5-6} is 16,282.26 lb

Segment End Weight (W_6)

$$W_6 = W_5 - W_{f5-6}$$

- W_6 is 84,967.18 lb

MS₆₋₇: Reserve (loiter)

Mission Segment Weight Fraction

- W_7/W_6 is 0.98

Fuel Burned Weight Fraction

- $1 - W_7/W_6$ is 0.02

Segment Start Weight (W_6)

- W_6 is 84,967.18 lb

Fuel Burned Weight MS₆₋₇

$$W_{f\ 6-7} = W_6 \times 0.02$$

$$W_{f\ 6-7} = 84967.18 \times 0.02$$

- W_{f6-7} is 1,963.85 lb

Segment End Weight (W_7)

$$W_7 = W_6 - W_{f\ 6-7}$$

- W_7 is 83,003.33 lb

MS₇₋₈: Descent

Mission Segment Weight Fraction

- W_8/W_7 is 0.993

Fuel Burned Weight Fraction

- $1 - W_8/W_7$ is 0.007

Segment Start Weight (W_7)

- W_7 is 83,003.33 lb

Fuel Burned Weight MS₇₋₈

$$W_{f\ 7-8} = W_7 \times 0.007$$

$$W_{f7-8} = 83003.33 * 0.007$$

- W_{f7-8} is 581.02 lb

Segment End Weight (W_8)

$$W_8 = W_7 - W_{f7-8}$$

- W_8 is 82,422.31 lb

MS₈₋₉: Land

Mission Segment Weight Fraction

- W_9/W_8 is 0.997

Fuel Burned Weight Fraction

- $1 - W_9/W_8$ is 0.003

Segment Start Weight (W_8)

- W_8 is 82,422.31 lb

Fuel Burned Weight MS₈₋₉

$$W_{f8-9} = W_8 \times 0.003$$

$$W_{f8-9} = 82422.31 * 0.003$$

- W_{f8-9} is 247.27 lb

Segment End Weight (W_9)

$$W_9 = W_8 - W_{f8-9}$$

- W_9 is 82,175.04 lb

To summarise the Fuel Weights per Mission Segment (for W_0 "GUESS" = 177,826.33 lb):

- W_{f0-1} is 4,279.17 lb
- W_{f1-2} is 2,743.38 lb
- W_{f2-3} is 21,808.94 lb
- W_{f3-4} is 12,558.08 lb
- W_{f4-5} is IGNORED
- W_{f5-6} is 16,282.26 lb
- W_{f6-7} is 1,963.85 lb
- W_{f7-8} is 581.02 lb
- W_{f8-9} is 247.27 lb

L.1.7.6. W_0 Determination: Total Fuel Weight

The total fuel weight is the sum of the fuel weights per Mission Segment, plus a small amount for reserves and “unusable fuel”.

Therefore (Equation 6.6):

$$W_{f \text{ mission}} = \sum_{x=1}^9 W_{f x}$$

Or, for this design:

$$W_{f \text{ mission}} = W_{f0-1} + W_{f1-2} + W_{f2-3} + W_{f3-4} + W_{f4-5} + W_{f5-6} + W_{f6-7} + W_{f7-8} + W_{f8-9}$$

Therefore, for W_0 “GUESS” = 142,639 lb:

$$W_{f \text{ mission}} = 4279.17 + 2743.38 + 21808.94 + 12558.08 + 0 + 16282.26 + 1963.85 + 581.02 + 247.27$$

- W_{mission} (all MS) is 60,463.96 lb

To account for unusable fuel in the tanks, a 6% “reserve factor” is applied to the total (Equation 6.7). Therefore, the total fuel weight for all MS (for W_0 “GUESS” = 142,639 lb) is:

$$W_f = 1.06 \times W_{f_{mission}}$$

- W_f is 64,091.79 lb

L.1.7.7. W_0 Determination: Empty Weight Fraction

As mentioned in sub-section M.1.7.1., the Empty Weight Fraction (W_e/W_0) is calculated according to the following Equation from Table 6.1:

$$W_e / W_0 = \{a + b \times W_0^{C1} \times AR_w^{C2} \times (T / W_0)^{C3} \times (W / S_{to})^{C4} \times M_{max}^{C5}\} \times K_{VS}, \text{ where:}$$

- a is 0.32 for a Jet Transport
- b is 0.66 for a Jet Transport
- $C1$ is -0.13 for a Jet Transport
- $C2$ is 0.3 for a Jet Transport
- $C3$ is 0.06 for a Jet Transport
- $C4$ is -0.05 for a Jet Transport
- $C5$ is 0.05 for a Jet Transport
- K_{VS} is 1 for a non-variable-sweep wing aircraft
- AR_w is 7.0, as previously determined
- T/W_0 is 0.35, as previously determined
- W/S_{to} is 120 lb/ft², as previously determined
- M_{max} is 0.9, as previously selected

- W_0 is W_0 “GUESS”, and is 142,639 lb

Therefore:

$$W_e / W_0 = \{0.32 + 0.66 * 142639^{-0.13} * 7.0^{0.3} * 0.35^{0.06} * 120^{-0.05} * 0.9^{0.05}\} * 1$$

- W_e/W_0 is 0.505803

L.1.7.8. W_0 Determination: Take-off Weight Calculation

As described under sub-section M.1.7.1., the take-off weight (W_{0_calc}) is now calculated using Equation 6.4:

$$W_{0_calc} = \frac{W_{crew} + W_{fixed_payload} + W_{dropped_payload} + W_{fuel}}{1 - (W_e / W_0)}$$

Therefore, for W_0 “GUESS” = 142,639 lb:

$$W_{0_calc} = \frac{0 + 3500 + 2900 + 64091.79}{1 - 0.505803}$$

- W_{0_calc} is 142,639.001 lb

This value is then compared with W_0 GUESS. New values for W_0 GUESS are chosen, until $W_{0_calc} = W_0$ GUESS. When this situation has been reached, W_0 has been determined.

- For the purposes of this concept design, W_0 is 142,639.001 lb

L.1.7.9. W_0 Determination: Weight Summary

This concept design therefore yields the following key weights:

- Take-off Weight (W_0): 142,639.001 lb
- Fuel Weight (W_f): 64,091.79 lb
- Zero Fuel Weight (W_{zfw}): 78,547.21 lb
- Empty Weight (W_e) (W_0 less all payloads): 72,147.21

L.1.8. Geometry

The following sub-sections determine the approximate geometry for the concept design, as per the methods described in Daniel P. Raymer's source material. Geometries determined include:

- Fuselage
- Wing
- Tail
 - Horizontal
 - Vertical

L.1.8.1. Geometry: Fuselage

The fuselage geometry is determined from Historical Data for Initial Sizing as follows (Table 6.3):

$$F_{length} = a \times W_0^c, \text{ where}$$

- a is 0.67 for a Jet Transport
- c is 0.43 for a Jet Transport

Therefore:

$$F_{length} = 0.67 * 142639.001^{0.43}$$

- F_{length} is 110.25 ft

As mentioned in Appendix K, determination of fuselage diameters for unmanned aircraft differs from manned aircraft primarily in the sense that manned aircraft require larger diameters to accommodate passengers. Suffice to say, unmanned aircraft tend to have smaller diameter fuselages. However, since fuselage diameter is not required as input to any further calculations using this method, it will not be calculated for this concept.

L.1.8.2. Geometry: Wing

The Reference Area for the wing (S_w) is calculated from the following Equation (Figure 4.15 and p. 84):

$$S_w = \frac{W_0}{(W / S_{to})}$$

Therefore:

$$S_w = \frac{142639.001}{120}$$

- S_w is 1188.66 ft²

The Wing Span (b_w) is calculated from (Equation 7.5):

$$b_w = \sqrt{AR_w \times S_w}$$

Therefore:

$$b_w = \sqrt{7.0 * 1188.66}$$

- b_w is 91.12 ft

The Taper Ratio for the wing (λ_w) is determined from historical data to lie between 0.2 and 0.3 for a swept wing. For the purposes of this design, λ_w is selected to be 0.23.

The Root Chord for the wing (c_{w_root}) is calculated from (Equation 7.6):

$$c_{w_root} = \frac{2 \times S_w}{b_w \times (1 + \lambda_w)}$$

Therefore:

$$c_{w_root} = \frac{2 * 1188.66}{91.12 * (1 + 0.23)}$$

- c_{w_root} is 21.21 ft

The Tip Chord for the wing (c_{w_tip}) is calculated from (Equation 7.7):

$$c_{w_tip} = \lambda_w \times c_{w_root}$$

Therefore:

$$c_{w_tip} = 0.23 * 21.21$$

- c_{w_tip} is 4.88 ft

The Wing Leading Edge Sweep angle (Λ_{w_LE}) is determined from Historical Data (Figure 4.19). From this figure, for a maximum Mach number of 0.9, Λ_{w_LE} is determined to be $\sim 30^\circ$.

The Wing Quarter Chord Sweep angle ($\Lambda_{w_C/4}$) is calculated from (Figure 4.16):

$$\Lambda_{w_C/4} = \arctan \left[\tan \Lambda_{w_LE} - \left\{ \frac{(1 - \lambda_w)}{AR_w \times (1 + \lambda_w)} \right\} \right]$$

Therefore:

$$\Lambda_{w_C/4} = \arctan \left[\tan(30^\circ \text{ radians}) - \left\{ \frac{(1 - 0.23)}{7.0 * (1 + 0.23)} \right\} \right]$$

- $\Lambda_{w_C/4}$ is 26°

The Mean Aerodynamic Chord for the wing (c_{w_MAC}) is calculated from (Equation 7.8):

$$c_{w_MAC} = (2/3) \times c_{w_root} \times \left[\frac{(1 + \lambda_w + \lambda_w^2)}{(1 + \lambda_w)} \right]$$

Therefore:

$$c_{w_MAC} = (2/3) * 21.21 * \left[\frac{(1 + 0.23 + 0.23^2)}{(1 + 0.23)} \right]$$

- c_{w_MAC} is 14.75 ft

The Aerodynamic Centre for the wing ($AeroC_w$) lies on the Mean Aerodynamic Chord, at a distance of 0.25 times the Mean Aerodynamic Chord from the leading edge, for subsonic flight (Figure 4.17).

Therefore:

- $AeroC_w$ is 3.69 ft from the leading edge, along the c_{w_MAC}

The Mean Aerodynamic Chord (and Aerodynamic Centre) lies at a distance Y from the fuselage centreline. Y_w is calculated from (Equation 7.9):

$$Y_w = \frac{b_w}{6} \times [(1 + 2 \times \lambda_w) \times (1 + \lambda_w)]$$

Therefore:

$$Y_w = \frac{91.12}{6} \times [(1 + 2 \times 0.23) \times (1 + 0.23)]$$

- Y_w is 27.27 ft

For the purposes of this concept design, the following parameters are selected as 0:

- Wing Twist (0°)
- Angle of Incidence (0°)

The Wing Location is selected as a Low Wing.

The Dihedral is selected from Table 4.2 to be 3° (for a Low Wing).

A Drooped Wing Tip is selected.

L.1.8.3. Geometry: Tail

The Tail is a combination of the Horizontal and Vertical tail surfaces. The geometries of both horizontal and vertical surfaces are described in the following sub-sections.

The concept design places the engines in pods at the rear of the fuselage (as per Method 1). However, this concept utilises a “T-tail” layout, to lift the horizontal tail surface above the wing wake and engine pods (p. 69 and Figure 4.29).

The tail areas are calculated utilising the Historical Values for the Tail Volume Coefficient (Table 6.4):

- Tail Volume Coefficient for Horizontal Tail (c_{HT}) is 1 (Jet Transport)
- Tail Volume Coefficient for Vertical Tail (c_{VT}) is 0.09 (Jet Transport)

The above values are for a conventional tail layout. A T-tail reduces the Tail Volume Coefficients for both surfaces by about 5% (p. 112). Therefore:

- c_{HT} is 0.95
- c_{VT} is 0.0855

The tail areas (S_{HT} and S_{VT}) are calculated as follows (Equations 6.29 and 6.28):

$$S_{HT} = \frac{c_{HT} \times c_{w_MAC} \times S_w}{L_{HT}}$$

$$S_{VT} = \frac{c_{VT} \times b_w \times S_w}{L_{VT}}, \text{ where}$$

- L_{HT} is the Horizontal Tail Arm (distance between the wing Aerodynamic Centre and the horizontal tail Aerodynamic Centre); for Initial Sizing, this value is determined from Historical Values as ~50% of the fuselage length, or 55.13 ft for this design. This is approximately 3½ times the Mean Aerodynamic Chord (Figure 4.29).
- L_{VT} is the Vertical Tail Arm (distance between the wing Aerodynamic Centre and the vertical tail Aerodynamic Centre); for Initial Sizing, this value is determined from Historical Values as ~45% of the fuselage length, or 49.61 ft for this design.

Therefore:

$$S_{HT} = \frac{0.95 * 14.75 * 1188.66}{55.13}$$

- S_{HT} is 302.11 ft²

$$S_{VT} = \frac{0.0855 * 91.12 * 1188.66}{49.61}$$

- S_{VT} is 186.65 ft²

The values for tail Aspect Ratio (AR_{HT} and AR_{VT}) and Taper Ratio (λ_{HT} and λ_{VT}) are determined from Historical Values for Initial Sizing (Table 4.3).

Therefore:

- AR_{HT} is 4
- AR_{VT} is 1.2
- λ_{HT} is 0.5
- λ_{VT} is 0.7

Tail spans (horizontal tail width b_{HT} and vertical tail height b_{VT}) are calculated from (Equation 7.5):

$$b = \sqrt{AR \times S}$$

Therefore:

$$b_{HT} = \sqrt{4 * 302.11}$$

- b_{HT} is 34.76 ft

$$b_{VT} = \sqrt{1.2 * 186.65}$$

- b_{VT} is 14.97 ft

As a check for horizontal tail positioning, from Figure 4.29: a horizontal T-tail with a Tail Arm of approximately $3\frac{1}{2}$ times the Mean Aerodynamic Chord (c_{w_MAC}), should be placed approximately $1.5 \times c_{w_MAC}$ ABOVE the wing. This is to avoid tail blanking by the wing during high angles of attack. Therefore:

$$b_{VT} \geq 1.5 * c_{w_MAC}$$

$$b_{VT} \geq 1.5 * 14.75$$

$$b_{VT} \geq 22.12 \text{ ft}$$

The calculated tail height (b_{VT}) of 14.97 is approximately 7 ft (or ~30%) lower than the check value. Since this UA will not be operated at high angles of attack, for the purposes of this concept design the calculated value will be kept, but should be re-evaluated during trade studies and additional design studies.

Root (c_{HT_root} and c_{VT_root}) and Tip (c_{HT_tip} and c_{VT_tip}) Chords for the tail surfaces are calculated as follows (Equations 7.6 and 7.7):

$$c_{root} = \frac{2 \times S}{b \times (1 + \lambda)}$$

$$c_{tip} = \lambda \times c_{root}$$

Therefore:

$$c_{HT_root} = \frac{2 * 302.11}{34.76 * (1 + 0.5)}$$

- c_{HT_root} is 11.59 ft

$$c_{VT_root} = \frac{2 * 186.65}{14.97 * (1 + 0.7)}$$

- c_{VT_root} is 14.67 ft

$$c_{HT_tip} = 0.5 * 11.59$$

- c_{HT_tip} is 5.79 ft

$$c_{VT_tip} = 0.7 * 14.67$$

- c_{VT_tip} is 10.27 ft

The Leading Edge Sweep angle on the horizontal tail surface (Λ_{HT_LE}) is estimated to be $\sim 5^\circ$ more than the wing Leading Edge Sweep angle (Λ_{w_LE}) (p. 76). Therefore:

- Λ_{HT_LE} is 35°

The Leading Edge Sweep angle on the vertical tail surface (Λ_{VT_LE}) is estimated to ~ 35 to 55° (p. 76). Therefore, for this design:

- Λ_{VT_LE} is 50°

The Quarter Chord Sweep angles ($\Lambda_{HT_C/4}$ and $\Lambda_{VT_C/4}$) for the tail surfaces are calculated as follows (Figure 4.16):

$$\Lambda_{C/4} = \arctan \left[\tan \Lambda_{LE} - \left\{ \frac{(1 - \lambda)}{AR \times (1 + \lambda)} \right\} \right]$$

Therefore:

$$\Lambda_{HT_C/4} = \arctan \left[\tan(35^\circ \text{ radians}) - \left\{ \frac{(1 - 0.5)}{4 * (1 + 0.5)} \right\} \right]$$

- $\Lambda_{HT_C/4}$ is 31.7°

$$\Lambda_{VT_C/4} = \arctan \left[\tan(50^\circ \text{ radians}) - \left\{ \frac{(1 - 0.7)}{1.2 * (1 + 0.7)} \right\} \right]$$

- $\Lambda_{VT_C/4}$ is 46.3°

The Mean Aerodynamic Chords (c_{HT_MAC} and c_{VT_MAC}) for the tail surfaces are calculated as follows (Equation 7.8):

$$c_{MAC} = (2/3) \times c_{root} \times \left[\frac{(1 + \lambda + \lambda^2)}{(1 + \lambda)} \right]$$

Therefore:

$$c_{HT_MAC} = (2/3) \times 11.59 \times \left[\frac{(1 + 0.5 + 0.5^2)}{(1 + 0.5)} \right]$$

- c_{HT_MAC} is 9.01 ft

$$c_{HT_MAC} = (2/3) \times 14.67 \times \left[\frac{(1 + 0.7 + 0.7^2)}{(1 + 0.7)} \right]$$

- c_{VT_MAC} is 12.6 ft

The Aerodynamic Centres for the tail surfaces ($AeroC_{HT}$ and $AeroC_{VT}$) lie on the tail surface Mean Aerodynamic Chords, at a distance of 0.25 times the Mean Aerodynamic Chord from the tail surface leading edge, for subsonic flight (Figure 4.17).

Therefore:

- $AeroC_{HT}$ is 2.25 ft from the horizontal tail surface leading edge, along the c_{HT_MAC}
- $AeroC_{VT}$ is 3.15 ft from the vertical tail surface leading edge, along the c_{VT_MAC}

The Mean Aerodynamic Chord (and Aerodynamic Centre) of each tail surface lie at a distance Y from the fuselage centreline. Y_{HT} and Y_{VT} are calculated from (Equation 7.9):

$$Y = \frac{b}{6} \times [(1 + 2 \times \lambda) \times (1 + \lambda)]$$

Therefore:

$$Y_{HT} = \frac{34.76}{6} \times [(1 + 2 \times 0.5) \times (1 + 0.5)]$$

- Y_{HT} is 17.38 ft

$$Y_{VT} = \frac{14.97}{6} * [(1 + 2 * 0.7) * (1 + 0.7)]$$

- Y_{VT} is 10.18 ft

L.1.9. Powerplant

A twin-turbofan-engine arrangement is selected for this concept design (same arguments as for Method 1).

Each engine is pod-mounted on the rear fuselage, as for Method 1. The pitch and cant angles with regards to the fuselage centreline for the engine pods are as follows (p. 209):

- Pitch angle: 2° up
- Cant angle: 2° out

L.1.9.1. Powerplant: Thrust Determination

The total minimum required take-off power (thrust, T_{0_tot}) at sea level is calculated from the previously determined Thrust-to-Weight Ratio at take-off (T/W_0) and Take-off Weight (W_0):

$$T_{0_tot} = W_0 \times (T / W_0), \text{ where}$$

- T/W_0 is 0.35
- W_0 is 142,639.001 lb

Therefore:

$$T_{0_tot} = 142639.001 * 0.35$$

- T_{0_tot} is 49,746.02 lbf

The minimum take-off thrust requirement per engine (T_{0_engine}) is therefore:

$$T_{0_engine} = \frac{T_{0_tot}}{2}$$

- T_{0_engine} is 24,873.01 lbf

This figure is rounded up to:

- T_{0_engine} is 25,000 lbf

L.1.9.2. Powerplant: Engine Selection

The engine selected for this concept design is the International Aero Engines IAE V2500 A1 turbofan. This engine satisfies the minimum take-off power requirement, and has the following characteristics:

- Maximum take-off thrust at sea level (T_{max}): 25,000 lbf
- Cruise thrust at 35,000 ft (T_{cruise}): 5,070 lbf
- Specific Fuel Consumption at take-off thrust at sea level (C_{max}): 0.35 lb/h/lbf (0.197 l/h/lbf)
- Specific Fuel Consumption at cruise thrust at 35,000 ft (C_{cruise}): 0.581 lb/h/lbf (0.326 l/h/lbf)
- Fan diameter (D_{engine_fan}): 1.681 m (66.18 in)
- Fan (engine front) area (A_{engine}): 3,439.98 in²
- Length (L_{engine}): 3.200 m (125.98 in)
- Basic weight (W_{engine}): 5,210 lb

L.1.9.3. Powerplant: Inlet Geometry

The inlet geometry (inlet capture area (A_{throat})) for a jet engine operating in subsonic airflow is determined from the following (Equations 10.16 and 10.17):

$$A_{throat} = A_{engine} \times \frac{(A/A^*)_{throat}}{(A/A^*)_{engine}}, \text{ where}$$

$$(A/A^*) = \frac{1}{M} \times \left(\frac{1 + 0.2 \times M^2}{1.2} \right)^3, \text{ where}$$

- For $(A/A^*)_{throat}$, M is 0.6 (p. 211)
- For $(A/A^*)_{engine}$, M is 0.4 (p. 211)

The air is slowed down from M_{cruise} (M0.71) to M0.6 outside the engine inlet (M0.6 at the throat/inlet face), and then to M0.4 inside the inlet. The engine fan face then receives air at M0.4.

Therefore:

$$(A/A^*)_{throat} = \frac{1}{0.6} * \left(\frac{1 + 0.2 * 0.6^2}{1.2} \right)^3$$

- $(A/A^*)_{throat}$ is 1.1882

$$(A/A^*)_{engine} = \frac{1}{0.4} * \left(\frac{1 + 0.2 * 0.4^2}{1.2} \right)^3$$

- $(A/A^*)_{engine}$ is 1.5901

Therefore:

$$A_{throat} = 3439.98 * \frac{1.1882}{1.5901}$$

- A_{throat} is 2,570.46 in²
- Inlet (throat) diameter (D_{inlet}) is 57.21 in (1.453 m)

L.1.9.4. Powerplant: Nozzle Geometry

The nozzle exit area (A_{nozzle}) for a non-afterburning subsonic jet engine is ~ 50 to 70% of the inlet capture area (A_{throat}) (p. 220). For the purposes of this design, a value of 70% A_{throat} was taken. Therefore:

- A_{nozzle} is 1,799.32 in²
- Nozzle diameter (D_{nozzle}) is 47.86 in (1.216 m)

L.1.10. Additional Performance Results

The total Range and Endurance can be calculated from the results obtained in previous calculations.

L.1.10.1. Additional Performance Results: Total Range

The total Range (R_{tot}) is determined as follows:

$$R_{\text{tot}} = R_{\text{cruise1}} + R_{\text{search_loiter}} + R_{\text{cruise2}} + R_{\text{reserve_loiter}}, \text{ where:}$$

- R_{cruise1} is 2,800 nm
- R_{cruise2} is 2,800 nm

It is assumed that climb and descent takes place over a vertical column, adding no additional useful range to the total.

$R_{\text{search_loiter}}$ and $R_{\text{reserve_loiter}}$ are determined from the respective loiter speeds and times as follows:

$$R_{\text{search_loiter}} = V_{\text{search_loiter}} \times E_{\text{search_loiter}}, \text{ where}$$

- $V_{\text{search_loiter}}$ is 710.98 ft/s (421.25 kn)
- $E_{\text{search_loiter}}$ is 4 h

Therefore:

$$R_{\text{search_loiter}} = 421.25 * 4$$

- $R_{\text{search_loiter}}$ is 1,685.02 nm

$R_{\text{reserve_loiter}} = V_{\text{reserve_loiter}} \times E_{\text{reserve_loiter}}$, where

- $V_{\text{reserve_loiter}}$ is 342.13 ft/s (202.71 kn)
- $E_{\text{reserve_loiter}}$ is 1 h

Therefore:

$$R_{\text{reserve_loiter}} = 202.71 \times 1$$

- $R_{\text{reserve_loiter}}$ is 202.71 nm

Therefore:

$$R_{\text{tot}} = 2800 + 1685.02 + 2800 + 202.71$$

- R_{tot} is 7,487.73 nm

L.1.10.2. Additional Performance Results: Total Endurance

The total Endurance (E_{tot}) is determined as follows

$E_{\text{tot}} = E_{\text{climb}} + E_{\text{cruise1}} + E_{\text{search_loiter}} + E_{\text{cruise2}} + E_{\text{reserve_loiter}} + E_{\text{descent}}$, where

- E_{climb} is 0.5 h (estimated time to climb from sea level to 35,000 ft)
- $E_{\text{search_loiter}}$ is 4 h
- $E_{\text{reserve_loiter}}$ is 1 h
- E_{descent} is 0.5 h (estimated time to descend to sea level from 35,000 ft)

E_{cruise1} and E_{cruise2} are determined from the respective cruise range and speed as follows:

$$E_{\text{cruise1}} = E_{\text{cruise2}} = \frac{R_{\text{cruise}}}{V_{\text{cruise}}}, \text{ where}$$

- R_{cruise} is 2,800 nm
- V_{cruise} is 467 kn

Therefore:

$$E_{\text{cruise1}} = E_{\text{cruise2}} = \frac{2800}{467}$$

- $E_{\text{cruise1}} = E_{\text{cruise2}}$ is 6 h

Therefore:

$$E_{\text{tot}} = 0.5 + 6 + 4 + 6 + 1 + 0.5$$

- E_{tot} is 18 h

Appendix M

M.Maritime Search and Rescue UAS Communications Scenario

Appendix M provides a graphical representation of the communications scenario for both Line-of-Sight and Beyond-Line-of-Sight situations, for a typical maritime Search and Rescue mission involving an unmanned aircraft.

SAR UAS Line-of-Sight Communications

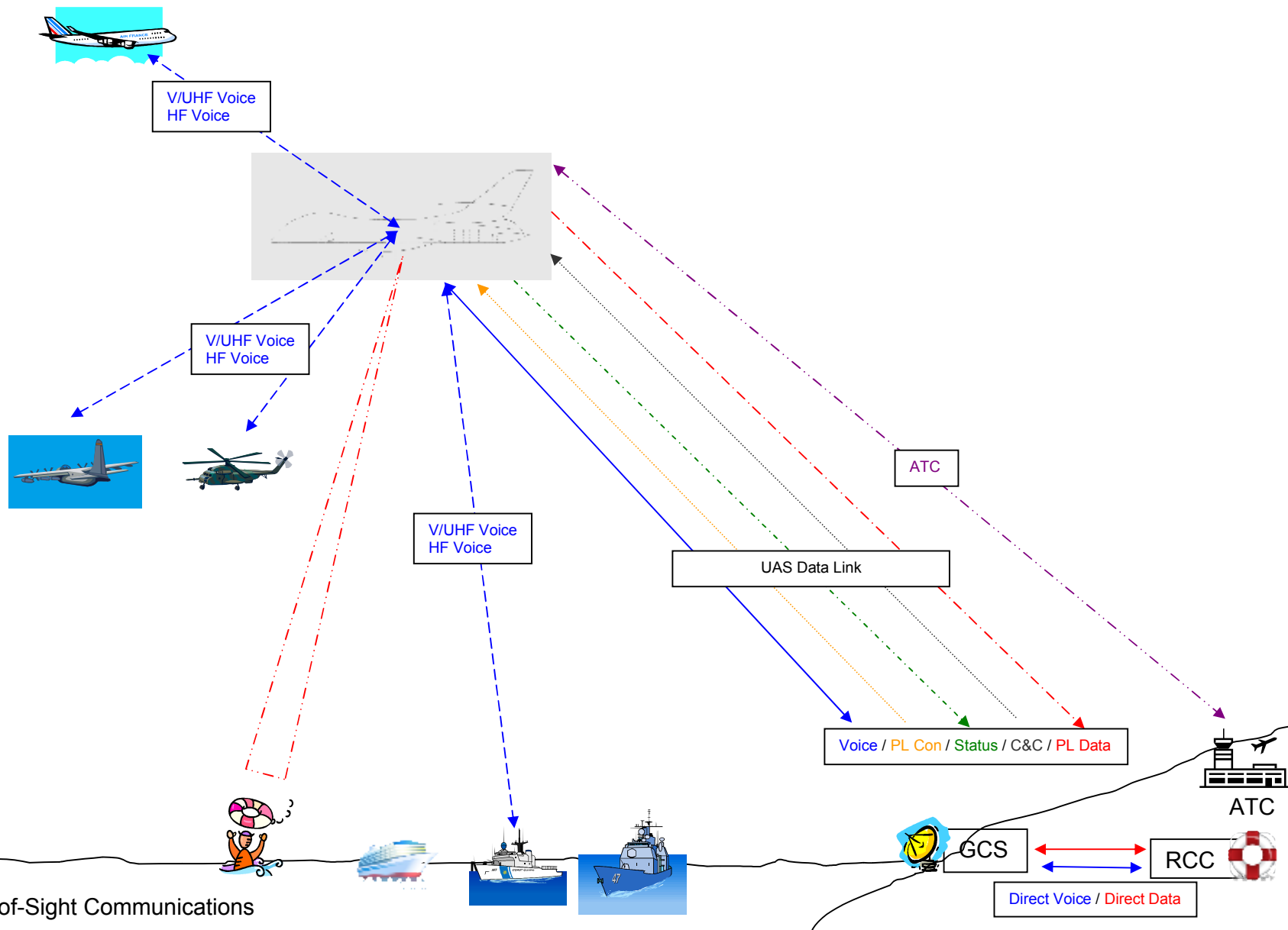


Figure M.1: Line-of-Sight Communications

SAR UAS Beyond Line-of-Sight Communications

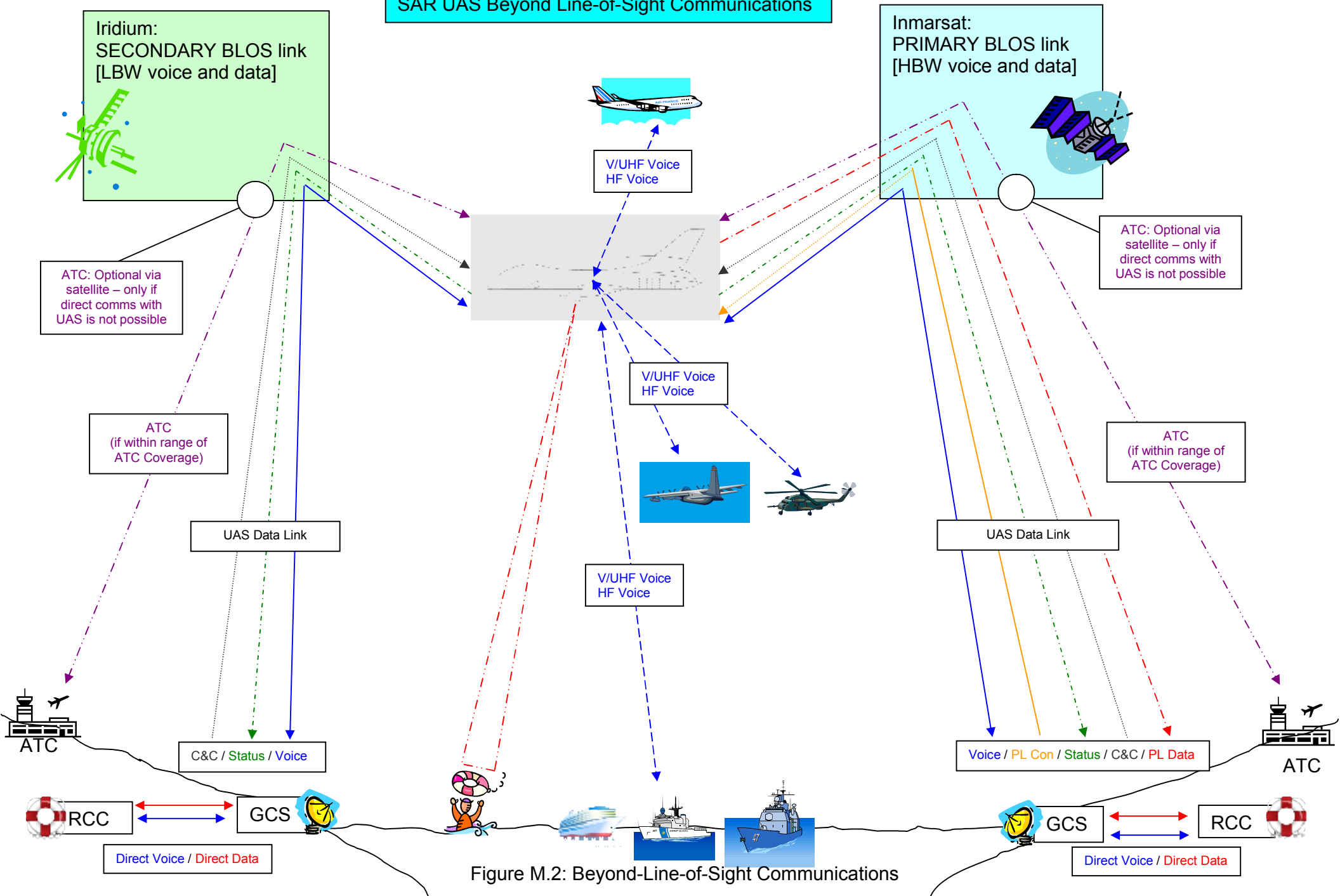


Figure M.2: Beyond-Line-of-Sight Communications

Appendix N

N. Unmanned Aircraft History

Appendix N provides additional details concerning the history of Unmanned Aircraft.

N.1. Pre-World War I Era

Although balloons are not regarded as true UAs, the first recorded use of unmanned aerial platforms was on 22 August 1849. The Austrians used unmanned balloons, filled with a payload of explosives, to bomb Venice. The balloons were launched from some distance away, and carried by wind currents to Venice, where they were detonated (with limited success)^[10].

N.2. World War I

World War I (WWI) introduced the concept of unmanned flying torpedoes and flying bombs. Effectively pilotless radio controlled aircraft, three types were developed between 1916 and 1917 – the Ruston Proctor “Aerial Target”, the Hewitt-Sperry Automatic Airplane (“Flying Bomb”), and the Dayton-Wright Kettering Bug (“Aerial Torpedo”). None of these designs were used operationally; the most successful of these being the Kettering Bug, which entered production as the War ended, thus never entering active service^{[11][12][13][15]}.

N.3. Interwar Period

Between World Wars I and II, the US and Britain developed a number of pilotless air vehicles, the most notable being^[14]:

- Larynx autopilot-controlled monoplane aircraft, launched from a warship and intended to act as an anti-ship weapon; it was developed between 1927 and 1929 by the British;
- Fairey “Queen” radio-controlled target, developed in 1931 by the British from the Fairey III floatplane;

- DH.82B “Queen Bee” radio-controlled target, developed in 1935 by the British from the DeHavilland Tiger Moth;

N.4. World War II

World War II (WWII) saw the first large scale production and use of pilotless aircraft (drones). The first of these was the Radioplane Company RP-1 aerial target, a radio controlled airplane developed in 1935 to provide an affordable means to train anti-aircraft gunners. Between 1938 and 1939 the RP-2, RP-3 and RP-4 were developed, leading to the development and deployment of nearly 15,000 Radioplane OQ-1 and OQ-2 drones (derivatives of the RP-4 and RP-5 respectively) during WWII. The US Navy derivative was the TDD-1 target drone. The Radioplane Company was bought by Northrop in 1952^[16].

The Curtiss N2C-2 target drone was developed between 1937 and 1938. N2C-2's were remotely piloted from another aircraft, the TG-2. Culver PQ-8 and PQ-14 target drones were also used by the US Army Air Force during the War. Meanwhile, the naval Aircraft Factory developed the first pilotless assault drones of WWII, although it never reached full operational status, having only limited “operational” tests conducted on beached targets by 1944. The concept involved an RCA television camera in the drone and a television screen in the TG-2 control aircraft. Torpedo and direct attacks were carried out with the TG-2 around 20 miles from the assault drone^{[16][17]}.

Around the middle of WWII, McDonnell developed the T2D2-1 Katydid, an air-launched pulsejet powered target. It was later developed into the KDD-1 and KDH-1. The Curtiss KD2C Skeet was another 1940's pulsejet design, but was put into service only after WWII had ended^[16].

N.5. Post WWII, Korean War and Vietnam War

During this period, the Radioplane Company developed a number of new target drones. These drones proved very successful and remained in service for the remainder of the 20th century, the most notable being the OQ-19/KD2R Quail, the MQM-33/MQM-36 Shelduck and the MQM-57 Falconer. The Globe Company developed the KDxG-series of target drones, the most notable being the KD6G drone^[16].

By 1952, Northrop had bought the Radioplane Company, and developed the Northrop Crossbow decoy drone. In 1957, McDonnell Aircraft Company developed the ADM-20 Quail air-launched decoy drone, which was produced in some numbers^{[16][19]}.

In order to keep pace with the development of supersonic aircraft, Northrop developed the GE J85-powered AQM-35 supersonic target drone in 1956^[10]. Northrop also developed the BQM-74 Chukar series subsonic target drones in 1965, with the F-series still in operation^{[16][18]}.

Various unmanned reconnaissance aircraft were developing during this period due to the success of the unmanned target drones. The most notable of these were the Aerojet-General MQM-58 "Overseer", the very successful Ryan Model 147 Lightning Bug series (developed from the equally successful Ryan BGM-34 Firebee unmanned platform), the Ryan "Model 154", the Ryan/Boeing "Compass Copes" and the Lockheed D-21^[18].

N.6. The Cold War

The Cold War, stretching from 1945 to 1991, saw a number of major conflicts, most notably the Korean and Vietnam wars, which led to the development of numerous unmanned target drones, reconnaissance and decoy drones, and attack drones, many of which have been mentioned in the preceding paragraphs. The 1980's saw the proliferation of genuine Battlefield UAs^[20].

N.7. Modern-day UAs

As mentioned, the 1980's saw a proliferation of true unmanned aircraft, most of them for military use. The first effective use of modern UAs was undertaken by the Israelis in the early 1980's during the Syrian War. The Israelis used UAs to gather information about Syrian air defence sites, and used Mastiff and Scout UAs to as decoys to draw enemy fire, allowing manned warplanes to destroy enemy surface-to-air missile sites. This prompted the USA to co-develop the RQ-2 Pioneer with Israel in 1984, which was introduced by 1986^[21].

The General Atomics Predator was the first UA to be deployed, in the Balkan conflict in 1995^[22], and it has seen extensive service in Afghanistan, Pakistan, Bosnia, Serbia, Iraq, and Yemen^[22]. Other UAs of note which have seen development and operational use during and since the 1980's include:

- Northrop Grumman RQ-4 Global Hawk (USA, 2006)^[22];
- General Atomics MQ-9 Reaper (USA, first flight 2001)^[22];
- General Atomics Ikhana (NASA civil UAV)^[23];
- General Atomics MQ-1C Sky Warrior (USA, first flight 2008)^[22];
- Israel Aircraft Industries RQ-5 Hunter (Israel)^[20];
- AAI Corporation RQ-7 Shadow (USA, first flight 1991)^[24];
- AAI/IAI RQ-2 Pioneer (Israel/USA, introduced in 1986)^[20];
- Israel Aircraft Industries Heron (Israel)^[25];
- Kentron Seeker I and II (South Africa, saw active service during Bush War in 1987)^[26];
- Northrop Grumman MQ-8 Fire Scout (USA, first flight 2002)^[24];
- Bell HV-911 Eagle Eye (USA, first flight 1998)^[27];

The 21st century also saw the development of many man-portable micro-UAs, capable of being hand- or shoulder-launched^[17]. An example of an in-service micro-UA is the US-developed AeroVironment RQ-11 Raven, introduced into active service in 2003^[28].

Appendix O

O. Unmanned Aircraft Categorisation

Appendix O provides additional details concerning the categorisation of Unmanned Aircraft.

O.1. TIER System

The United States Air Force (USAF), United States Marine Corps (USMC) and United States Army (US Army) have developed and adopted the “TIER” system to categorise their UAs^[29]. Problem is, even the TIER system is not standardised among the three Arms of Force, each one differing to a degree from the other^[29]. The following provides a brief summary of the various TIER-categories for all three Arms of Force, with examples^[29].

O.1.1. TIER N/A UA

- USAF: Small or Micro UA
 - AeroVironment Wasp III Micro Air Vehicle (MAV)
- USMC: Micro UA
 - AeroVironment Wasp III MAV
- US Army: Currently not used

O.1.2. TIER I UA

- USAF: Low altitude, long endurance (LALE) UA
 - General Atomics GNAT 750
- USMC: Similar to US Army TIER I - Small UA
 - AeroVironment Dragon Eye
 - AeroVironment RQ-11B Raven B
- US Army: Small UA

- AeroVironment RQ-11B Raven B

O.1.3. TIER II UA

- USAF: Medium altitude, long endurance (MALE) UA
 - General Atomics MQ-1 Predator
 - General Atomics MQ-9 Reaper
- USMC: Similar to US Army TIER II - Short range tactical UA
 - Insitu/Boeing ScanEagle
 - AAI/IAI RQ-2 Pioneer
- US Army: Short range tactical UA
 - AAI Corporation RQ-7B Shadow 200

O.1.4. TIER II+ UA

- USAF: High altitude, long endurance (HALE) UA – typical specifications include 60,000 to 65,000ft altitude, 3,000nmi operational radius, 24hr time-on-station, 300kn maximum airspeed.
 - Northrop Grumman RQ-4 Global Hawk
- USMC: Currently not used
- US Army: Currently not used

O.1.5. TIER III- UA

- USAF: High altitude, long endurance (HALE) low-observable (stealth) UA – typical specifications include 60,000 to 65,000ft altitude, 3,000nmi operational radius, 24hr time-on-station, 300kn maximum airspeed.
 - Lockheed Martin RQ-3 DarkStar
- USMC: Currently not used

- US Army: Currently not used

O.1.6. TIER III UA

- USAF: Currently not used
- USMC: Medium range tactical UA
 - AAI/IAI RQ-2 Pioneer
 - AAI Corporation RQ-7B Shadow 200
- US Army: Medium range tactical UA
 - Israel Aircraft Industries RQ/MQ-5 Hunter
 - General Atomics I-GNAT ER
 - General Atomics MQ-1C Sky Warrior

O.2. Function, Purpose, Mission, Task or Role

UAs can also be categorised by function, purpose, mission, task or role (in short, its intended use). The following provides a brief summary of how this categorisation method is applied, with examples^[29].

O.2.1 Target and/or Decoy UA

O.2.1.1 Target UA

Provides a physical and visual cue to ground and aerial gunnery for training purposes; it simulates an aircraft or weapon^{[18][30]}.

- Northrop Grumman BQM-74F Chukar III
- Beech BQM-107E Streaker
- Composite Engineering Inc BQM-167A Skeeter
- Meteor Mirach 100/5
- Denel Dynamics Skua

O.2.1.2. Decoy UA

Provides a decoy to ground-based- or airborne air defences, thereby drawing attention away from allied manned or unmanned aircraft pursuing a particular mission^[19].

- Brunswick ADM-141C ITALD
- Northrop Grumman ADM-160B MALD

O.2.2. Reconnaissance/Surveillance UA

These UAs are deployed to scout areas and provide vital information to interested parties. It is synonymous with military operations, where reconnaissance parties are sent into enemy territories to scout and report back vital information necessary for the successful execution of an operation. Information includes location of logistic supply lines, ammunition depots, bases, personnel strengths and movements, defences, assets and current tactics. It is usually of short duration, and takes a “snap-shot” of the current situation^{[31][32]}.

Surveillance also involves the gathering of vital information, but is focussed on long-term behaviour and activity, and other changing information. It takes place over a prolonged period of time. It is often used to recognise and monitor potential threats, and to prevent or investigate criminal activity^{[33][34]}.

- Lockheed D-21 Tagboard (strategic recon)^[35]
- Tupolev Tu-300 Korshun (strategic recon)^[35]
- AAI/IAI RQ-2 Pioneer (tactical surv & recon)^[20]
- AAI Corporation RQ-7B Shadow 200 (tactical surv & recon)^[24]
- Northrop Grumman MQ-8B Fire Scout (tactical surv & recon)^[24]
- Insitu/Boeing ScanEagle (tactical surv & recon)^[27]
- Denel Dynamics Seeker (tactical surv & recon)

- General Atomics RQ/MQ-1 Predator (strategic surv & recon)^[22]
- General Atomics MQ-1C Sky Warrior (strategic surv & recon)^[22]
- Lockheed Martin RQ-3 DarkStar (strategic surv & recon)^[22]
- Northrop Grumman RQ-4 Global Hawk (strategic surv & recon)^[22]
- EADS/IAI Eagle 2 (strategic surv & recon)^[25]

O.2.3. Combat UA

Combat-capable UAs are designed to carry and deliver weapons, usually precision strike. They are commonly referred to as Unmanned Combat Air Vehicles, or UCAVs. They are typically employed in situations proving too risky or outright dangerous for manned combat aircraft^[29].

- Boeing X-45A (technology demonstrator only)^[36]
- Northrop Grumman X-47B (in development)^[36]
- BAE Systems Mantis (mock-up only)^[36]
- BAE Systems Taranis (in development)^[36]
- General Atomics MQ-9 Reaper^[22]

O.2.4. Logistic Supply UA

These UAs are designed to carry cargo and provide support to logistics operations.

- Boeing A160 Hummingbird^[24]
- AAI Corporation RQ-7B Shadow 200 with Quick-MEDS^[24]

O.2.5. Research and Development UA

These UAs are used solely to develop new technologies, to be integrated at some later stage in operational systems.

- Boeing X-45A (UCAV technology)^[36]
- Northrop Grumman X-47A Pegasus (UCAV technology)^[36]
- Boeing X-50A Dragonfly (rotor-wing technology)^[24]
- Sikorsky Cypher (VTOL technology)^[27]
- NextGen Aeronautics MFX-1 (morphing wings)^[27]
- Boeing Condor (endurance)^[37]
- Lockheed Martin RQ-3 DarkStar (low observability with endurance)^[22]
- AeroVironment Helios (solar powered UA)^[39]
- AeroVironment Global Observer (hydrogen powered UA)^[39]

O.2.6. Civil and Commercial UAs

These are used for civilian and commercial purposes.

- General Atomics Ikhana (USFS/NASA; forest fire observation)^[22]
- Insitu Aerosonde (metrological/weather observations)^[27]
- Bell HV-911 Eagle Eye (US Coast Guard; considering)^[27]
- Northrop Grumman RQ-4A Global Hawk (NASA; earth sciences)^[22]
- Northrop Grumman RQ-4A Global Hawk (US Coast Guard; considering)^[38]
- Elbit Systems Hermes 450 (US Border Patrol)^[25]
- Aurora Flight Services Perseus-A/B (NASA; high altitude environmental impact studies)^[39]
- Aurora Flight Services Theseus (NASA; environmental observation)^[39]

- General Atomics Altus II (NASA; high altitude propulsion and performance)^[39]

O.3. Performance

UAs can also be categorised by altitude, range and/or endurance, and/or other basic performance parameters. The following provides a brief summary of how this categorisation method is applied, with examples^{[29][83]}.

O.3.1. Handheld

- Altitude: 2,000ft
- Range: 2km
- Endurance: unspecified
- Other: unspecified
- Examples:
 - AeroVironment Wasp III^[40]

O.3.2. Close

- Altitude: 5,000ft
- Range: 10km
- Endurance: unspecified
- Other: unspecified
- Examples:
 - AeroVironment Raven RQ-11B^[41]

O.3.3. NATO Type

- Altitude: 10,000ft
- Range: 50km

- Endurance: unspecified
- Other: unspecified
- Examples:
 - BAI Aerosystems BQM-147 Dragon Drone^[24]
 - BAI Aerosystems Viking 400^[42]

O.3.4. Tactical

Altitude: 18,000ft

- Range: 160km
- Endurance: unspecified
- Other: unspecified
- Examples: Denel Dynamics Seeker II^[43]
 - AAI/IAI RQ-2 Pioneer^[44]
 - AAI Corporation RQ-7B Shadow 200^[45]
 - Northrop Grumman MQ-8B Fire Scout^[45]
 - Insitu/Boeing ScanEagle^[47]

O.3.5. Medium Altitude, Long Endurance (MALE)

- Altitude: 30,000ft
- Range: over 200km
- Endurance: “long endurance” (but unspecified)
- Other: unspecified
- Examples:

- General Atomics RQ/MQ-1 Predator^[48]
- General Atomics MQ-1C Sky Warrior^[49]
- IAI Malat Heron 1^[50]
- Denel Dynamics Bateleur^[51]

O.3.6. High Altitude, Long Endurance (HALE)

- Altitude: over 30,000ft
- Range: indefinite
- Endurance: “long endurance” (but unspecified)
- Other: unspecified:
- Examples:
 - General Atomics MQ-9 Reaper (also “Advanced MALE”)^[52]
 - Lockheed Martin RQ-3A DarkStar^[22]
 - Northrop Grumman RQ-4 Global Hawk^[53]
 - IAI Malat Heron TP (also “Advanced MALE”)^[54]
 - Aurora Flight Services Theseus^[39]
 - General Atomics Altus II^[39]

O.3.7. High Speed

- Altitude: 50,000ft to sub-orbital
- Range: over 200km
- Endurance: unspecified
- Other: subsonic: up to Mach 1; supersonic: Mach 1 to 5; hypersonic: over Mach 5

- Examples:
 - Boeing X-45A/B – subsonic^[55]
 - Northrop Grumman X-47B – subsonic^[56]
 - Dassault Neuron – subsonic^[57]
 - Composite Engineering Inc BQM-167A Skeeter – subsonic^[18]
 - Beech AQM-37C Jayhawk – supersonic^[18]

O.3.8. Orbital

- Altitude: low-earth orbit
- Range: unspecified
- Endurance: unspecified
- Other: over Mach 25
- Examples:
 - n/a

O.3.9. CIS-Lunar

- Altitude: Earth-Moon transfer
- Range: Moon
- Endurance: unspecified
- Other: unspecified
- Examples:
 - n/a

The performance figures per category are not rigid, but serve as a guide. Some UAs falling within a specific performance category may have other

performance figures that fall outside the limits, but remain eligible for that category. An example is the Denel Dynamics Seeker II, which falls within the “Tactical” category, but which has a range figure in excess of the specified “limit”.

A single UA can be categorised either according to one, or a combination of, categorisation methods. As an example, the Northrop Grumman RQ-4 Global Hawk can be categorised as a TIER II+ Reconnaissance/Surveillance AND/OR Civil/Commercial HALE UA, or any combination thereof, depending on the circumstances.